AMERICAN TELEPHONE PRACTICE

BY

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PREFACE.

THE intended scope of this book is set forth in its title. To those interested the writer has endeavored to present in as clear a manner as possible the general principles of telephony, the design and construction of commercial apparatus, the circuits connecting such apparatus into operative systems, and the methods used in the construction, operation, and maintenance of these systems. No attempt whatever has been made to treat the subject from its purely mathematical standpoint, that being beyond the scope of this work. The apparatus and methods of both Bell and Independent companies have been given impartial attention.

The writer sincerely thanks his friends, Mr. Wm. H. Donner and Mr. Wm. R. Mackrille, for their many suggestions and untiring labors in proof reading, and also Mr. W. D. Weaver, editor of the *Electrical World and Engineer*, for his interest and assistance throughout the entire preparation of this book.

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AMERICAN TELEPHONE PRACTICE.

CHAPTER I.

HISTORY AND PRINCIPLES OF THE MAGNETO TELEPHONE.

THE history of the telephone, from its inception to its present state of perfection, is interesting in the extreme, and affords a striking example of the fact that great inventions are almost invariably the result of long and careful study on the part of many workers, rather than the sudden inspiration of a single genius. It is of even greater interest from a scientific standpoint, for in no way can one obtain a better idea of the fundamental principles involved in telephony than by following their development, step by step, noting the contributions made by each of the many scientists and inventors whose names are closely connected with electrical progress.

These steps were made in logical order, the knowledge contributed by each investigator making possible a deeper insight into the subject on the part of his successors. It is best, therefore, to follow this order in obtaining primary ideas of the subject.

The history of the knowledge of electromagnetism begins with July 20, 1820, and with this date very properly begins the history of the electric telephone. On that day Oersted, a professor in the University of Copenhagen, discovered that a magnetic needle tends to place itself at right angles to a wire carrying a current of electricity. Ampere immediately took up the subject, and in a very short time developed the laws upon which present electromagnetic theory is based.

In the following year Arago and Davy discovered that if a current be caused to flow through an insulated wire wrapped about a rod of steel the latter would exhibit magnetic properties. It was William Sturgeon, however, who in 1825 made an electromagnet as we know it to-day, and called it by that name. To these three men, therefore, belongs the credit of one of the greatest discoveries in the history of science. Joseph Henry also made

his classic experiments on the electromagnet, and to him must be accredited a large amount of our knowledge regarding it. Henry showed how to build a magnet capable of being operated over a great length of wire, a most important step.

In 1831 Faraday and Henry, independently, discovered the converse of these laws of electromagnetism—that if the intensity of a magnetic field inclosed by a conductor be in any wise changed, a current of electricity will flow in said conductor. This current will flow only while such change is taking place, and its strength will depend directly on the rate of the change.

These two laws concerning the transformation of electric energy into magnetic, and its converse, the transformation of magnetic energy into electric, are certainly the most important in the whole realm of electrical science; as singly or together they form the foundations not only of the telephone and telegraph, but of electric lighting, electric power transmission, and

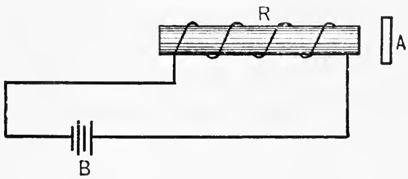


Fig. 1.—Sturgeon-Electromagnet.

of every other achievement by which electricity has revolutionized the methods of life throughout the whole civilized world.

As these laws form the very root of all telephone practice, a few illustrations directly in line with the principles of the telephone will not be amiss, even though they are very generally understood; for they will give a clearer understanding of the developments made by subsequent inventors. If, as shown in Fig. 1, a coil of wire be wrapped around a rod, *R*, of iron or steel, and a battery, *B*, placed in circuit with the coil, the rod becomes a magnet upon the closure of this circuit, and will attract an iron armature, *A*, in the vicinity of either of its poles. Any variation in the strength of this current will cause corresponding variations in the attractive power of the magnet. If the rod be of steel, and permanently magnetized, it will exert an attractive force of its own on the armature, and the current will, according to its direction, increase or diminish this attractive force.

About every magnet there exists a field of force; that is, a region in which any body capable of being magnetized (such as

iron) has exerted on it, by the magnet, an influence of attraction or repulsion. This field of force is usually graphically represented by closed curves, radiating from the poles of the magnet, and the strength of the magnet is commonly measured in terms of the number of such lines radiating from one of its poles. A magnet may be made to map out its own field of force by placing it in a horizontal position and directly over it a sheet of

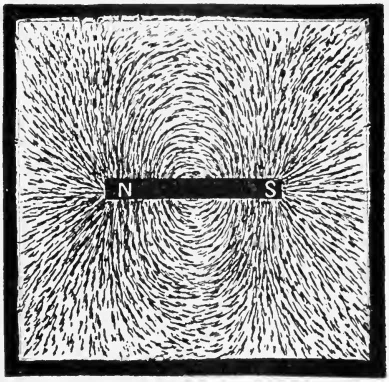


Fig. 2.—Lines of Force of Bar-Magnet.

paper or cardboard. If iron filings are then dropped from a height of a few feet, on the paper, they will arrange themselves in the direction of the lines of force. Fig. 2 shows such a map produced by the bar-magnet, *N S*.

If now a galvanometer, *G*, or other current-indicator (Fig. 3) be placed in circuit with a coil, *C*, and a magnet, *N S*, moved in

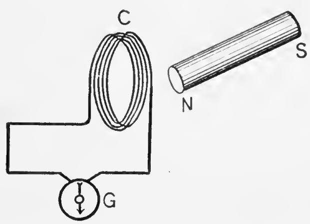


Fig. 3.—Faraday and Henry Magneto-Electricity.

the vicinity of the coil, or the coil in the vicinity of the magnet, in such manner as to change the number of lines of force passing through the coil, a current is generated in the coil and is indicated by the galvanometer. This current will flow only while

the magnet is being so moved. Its direction will depend on the direction of the lines of force threading the coil and on whether their number is being increased or diminished. Its strength will depend on the rate at which their number is changing.

If a mass of iron be brought within the field of a magnet, the field becomes distorted by virtue of a larger number of lines finding their path through the space occupied by the iron than through the same space when filled with air. Therefore, if a closed coil be placed about a pole of the magnet and a body of iron be moved to and from the pole, the intensity of the field in which the coil lies will vary, and currents of electricity will flow in the coil.

In 1837 Professor Page of Salem, Mass., discovered that a rod of iron, suddenly magnetized or demagnetized, would emit certain

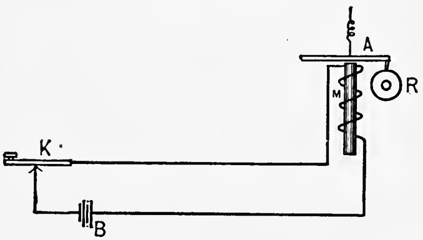


Fig. 4.—Morse Electromagnetic Telegraph.

sounds due to a molecular rearrangement caused by the changing magnetic conditions. This phenomenon is known as "Page's effect."

Late in the thirties Professor S. F. B. Morse placed at one end of a line Sturgeon's electromagnet, *M* (Fig. 4), with a pivoted armature, *A*, and at the other end a battery, *B*, and a key, *K*, for making and breaking the circuit. By manually closing and opening the key, the core of the magnet became magnetized and demagnetized, thus alternately attracting and releasing the armature. By this means signals were sent and recorded on a strip of paper, carried on a roller, *R*, in front of the armature, and thus intelligence was practically conveyed by electrical means between distant points.

In 1854 a Frenchman, Charles Bourseul, predicted the transmission of speech, and outlined a method correct save in one particular, but for which error one following his directions could have produced a telephone of greater efficiency than that subsequently devised by Bell. His words at this date seem almost prophetic: "Suppose a man speaks near a movable disk suffi-

ciently flexible to lose none of the vibrations of the voice, and that this disk alternately *makes and breaks* the current from a battery; you may have at a distance another disk which will simultaneously execute the same vibrations."

Philip Reis, a German inventor, constructed a telephone in 1861, following very closely the path outlined by Bourseul. He mounted a flexible diaphragm, *D* (Fig. 5) over an opening in a

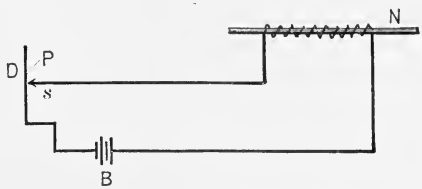
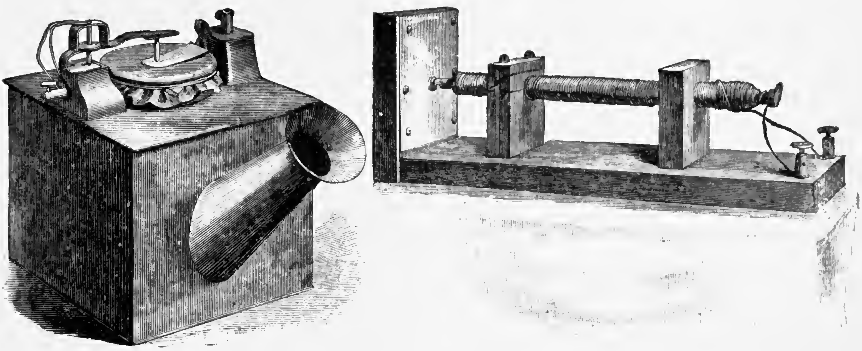


Fig. 5.—Reis' Make-and-Break Telephone.

wooden box, and on the center of the diaphragm fastened a small piece of platinum, *P*. Near this he mounted a heavy brass spring, *s*, with which the platinum alternately *made and broke* contact when the diaphragm was caused to vibrate. These contact points formed the terminals of a circuit containing a battery, *B*, and the receiving instrument. His receiver assumed various forms, prominent among which was a knitting needle, *N*, wrapped with


Figs. 6. and 7.—Reis' Telephone Transmitter and Receiver.

silk-insulated copper wire and mounted on a cigar box for a sounding board. Its operation was as follows: The sound waves set up by the voice struck against the diaphragm of the transmitter, causing it to vibrate in unison with them. This made and broke the circuit at the contact points, and allowed intermittent currents to flow through the receiver. The currents,

which exactly synchronized with the sound waves, caused a series of sounds in the knitting needle by virtue of "Page's effect." The sounding board vibrated in unison with the molecular vibrations of the needle, and the sound was thus greatly amplified. Reis' transmitter and one form of his receiver are shown in Figs. 6 and 7 respectively.

Reis' telephone could be depended upon to transmit only musical sounds, but it is probable that it did actually transmit articulate speech. The cause of this partial failure will be understood from the following facts:

A simple musical tone is caused by vibrations of very simple form, while sound waves produced by the voice are very complex in their nature. These two forms of waves are shown graphically in Fig. 8.

Sound possesses three qualities: pitch, depending entirely on the frequency of the vibrations; loudness, depending on the

Fig. 8.—Sound Waves of Voice and Simple Musical Note.

amplitude of the vibrations, and timbre or quality, depending on the form of the vibration. The tones of a flute and a violin may be the same as to pitch and loudness and yet be radically different. This difference is in timbre or quality.

Reis' transmitter, as he adjusted it, was able only to make and break the circuit, and a movement of the diaphragm barely sufficient to break the circuit produced the same effect as a much greater movement. The current therefore flowed with full strength until the circuit was broken, when it stopped entirely. The intermediate strengths needed for reproducing the delicate modulations of the voice were entirely wanting. This apparatus could therefore exactly reproduce the pitch of a sound, but not its timbre and relative loudness.

For the next fifteen years no great advance was made in the art of telephony, although many inventors gave it their careful attention.

In 1876 Professor Alexander Graham Bell and Professor Elisha Gray almost simultaneously invented successful speaking

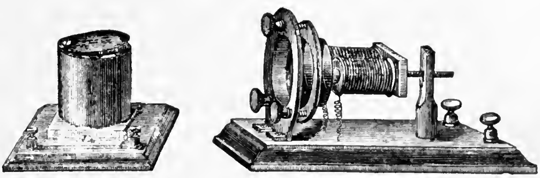
telephones. Bell has, however, apparently reaped the profit, the U. S. Patent Office having awarded priority of invention to him.

Bell possessed a greater knowledge of acoustics than of electrical science, and it was probably this that led him to appreciate wherein others had failed. His instrument consisted of a permanent bar-magnet, *B* (Fig. 9), having on one end a coil of fine wire. In front of the pole carrying the coil a thin diaphragm, *D*, of soft iron was so mounted as to allow its free vibration close

Fig. 9.—Bell-Magneto-Telephone.

to the pole. Two of the instruments are shown connected in a circuit in Fig. 9.

Two points will be noticed which have heretofore been absent: that no battery is used in the circuit, and that the transmitting and receiving instruments are exactly alike. When the soft-iron diaphragm of the transmitting instrument is spoken to, it vibrates in exact accordance with the sound waves striking against it. The movement of the diaphragm causes changes in the magnetic field in which lies the coil, which changes, as shown above, cause an alternating current to flow in the circuit. This current varies in unison with the movements of the diaphragm. The waves of this current are very complex, and represented graphically are similar to those of the voice shown in Fig. 8. Passing along the line wire, these electrical impulses, so feeble that only the most delicate instruments can detect them, alternately increase and de-



Figs. 10. and 11.—Bell's Early Receiver and Transmitter.

crease the strength of the permanent magnet of the receiving instrument, and thereby cause it to exert a varying pull on its soft-iron diaphragm, which, as a result, takes up the vibrations and reproduces the sound faithfully. Bell's earlier instruments, exhibited in 1876 at the Centennial in Philadelphia, are shown in Figs. 10 and 11, the former being his receiver, the latter his

transmitter. The receiver consisted of a tubular magnet composed of a coil of wire surrounding a core, and inclosed in an iron tube. This tube was closed by a thin iron armature or diaphragm as shown. The transmitter consisted of an electromagnet, in front of which was adjustably mounted a diaphragm of gold-beater's skin carrying a small iron armature in its center.

Bell's instrument, in a modified form, is the standard of to-day. It is now used as a receiver only, a more efficient transmitter, depending upon entirely different principles, having been invented.

In speaking of Bell's invention Lord Kelvin has said: "Who can but admire the hardihood of invention which devised such very slight means to realize the mathematical conception that if

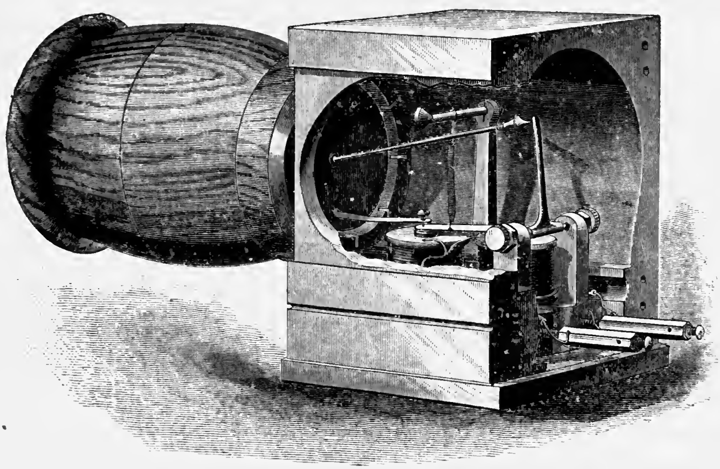


Fig. 12.—Royal E. House's Electro-Phonetic Telegraph.

electricity is to convey all the delicacies of quality which distinguish articulate speech, the strength of its current must vary continuously as nearly as may be in simple proportion to the velocity of a particle of air engaged in constituting the sound?"

A very interesting fact, and one which might have changed the entire commercial status of the telephone industry is that in 1868 Royal E. House of Binghamton, N. Y., invented and patented an "electro-phonetic telegraph," which was capable of operating as a magneto-telephone, in the same manner as the instruments subsequently devised by Bell. House knew nothing of its capabilities, however, unfortunately for him. The instrument is shown in Fig. 12, and is provided with a sound-

ing diaphragm of pine wood stiffened with varnish, mounted in one end of a large sound-amplifying chamber so formed as to focus the sound waves at a point near its mouth, where the ear was to be placed to receive them. The electromagnet adapted to be connected in the line circuit had its armature connected by a rod with the center of the wooden diaphragm as shown. By this means any movements imparted to the armature by fluctuating currents in the line were transmitted to the diaphragm, causing it to give out corresponding sounds; and any movements imparted to the diaphragm by sound waves were transmitted to the armature, causing it to induce corresponding currents in the line. Two of these instruments connected in a circuit as shown in Fig. 9 would act alternately as transmitters and receivers in the same manner as Bell's instruments.

CHAPTER II.

HISTORY AND PRINCIPLES OF THE BATTERY TRANSMITTER.

It has been shown that in order to transmit speech by electricity it is necessary to cause an undulatory or alternating current to flow in the circuit over which the transmission is to be effected, and that the strength of this current must at all times be in exact accordance with the vibratory movements of the body producing the sound.

Bell's transmitter was used as the generator of this current; as a dynamo, in fact, the energy for driving which was derived from the sound waves set up by the voice. The amount of energy so derived was, however, necessarily very small and the current correspondingly weak, and for this reason this was not a practical form of transmitter, except for comparatively short lines.

Elisha Gray devised a transmitter which, instead of generating the undulatory current itself, simply served to cause variation in the strength of a current generated by some separate source.

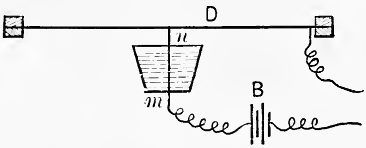


Fig. 13.—Gray's Variable Resistance Transmitter.

He accomplished this by mounting on his vibrating diaphragm, *D* (Fig. 13), a platinum needle, *n*, the point of which was immersed in a fluid of rather low conductivity, such as water. The variable distance to which the needle was immersed in the fluid, due to the vibration of the diaphragm, caused changes in the resistance of the path through the fluid, and corresponding changes in the strength of the current set up in the circuit by the battery, *B*. Instead of making and breaking the circuit, as did the transmitter of Reis, this instrument simply caused variations in the resistance of the circuit, and thereby allowed a continuous but undulatory current to pass over the line. The variations in this current conformed exactly with the sound waves acting upon the diaphragm, and were, therefore, capable of reproducing all

the delicate shades of timbre, loudness, and pitch necessary in articulate speech.

Gray embodied in this apparatus the main principle upon which all successful battery transmitters are based, but it was not long before a much better means was devised for putting it into practice.

In 1877 Émile Berliner of Washington, D. C., applied for a patent on a transmitter depending upon a principle previously pointed out by the French scientist, Du Moncel, that if the pressure between two conducting bodies forming part of an electric circuit be increased, the resistance of the path between them will be diminished, and conversely, if the pressure between them be decreased, a corresponding increase of resistance will result.

Berliner's transmitter is shown in Fig. 14, which is a reproduction of the principal figure in his now famous patent and in which

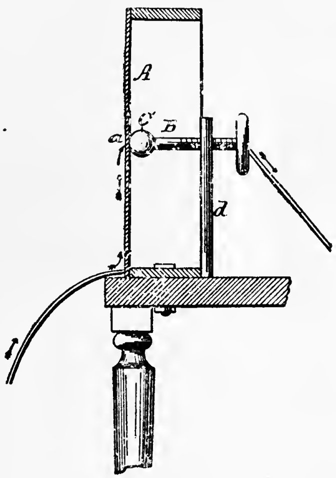
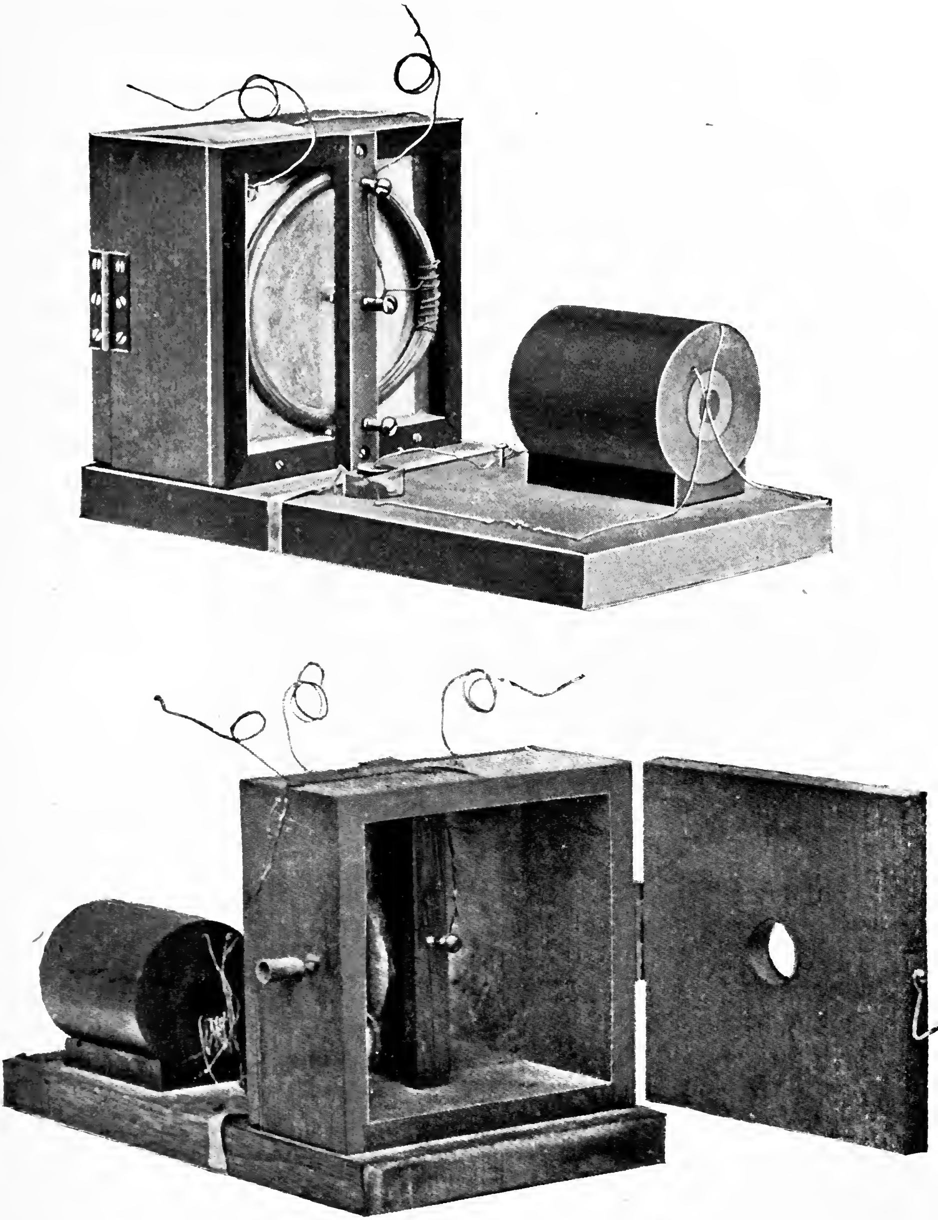


Fig. 14.—Berliner's Transmitter.

A is the vibratory diaphragm of metal, against the center of which rests the metal ball, *C*, carried on a thumb-screw, *B*, which is mounted in the standard, *d*. The pressure of the ball, *C*, against the plate, *A*, can be regulated by turning the thumb-screw. The diaphragm and ball form the terminals or electrodes of a circuit, including a battery and receiving instrument. Figs. 15 and 16 show two different views of an exact duplicate of Berliner's original model as filed in the patent office. This was very roughly constructed as shown. The diaphragm was a circular piece of ordinary tin and the contact-piece a common blued-iron wood screw.



Figs. 15. and 16.—Berliner's Patent-Office Model.

The action of this instrument is as follows: when the diaphragm is vibrating, the pressure at the point of contact, *a*, becomes greater or less, thus varying the resistance of the contact and causing corresponding undulations in the current flowing.

Soon after this Edison devised an instrument using carbon as the medium for varying the resistance of the circuit with changes of pressure. Edison's first type of carbon transmitter consisted simply of a button of compressed plumbago bearing against a small platinum disk secured to the diaphragm. The plumbago button was held against the diaphragm by a spring, the tension of which could be adjusted by a thumb-screw.

A form of Edison's transmitter, devised by George M. Phelps in 1878, is shown in Fig. 17. The transmitting device proper is

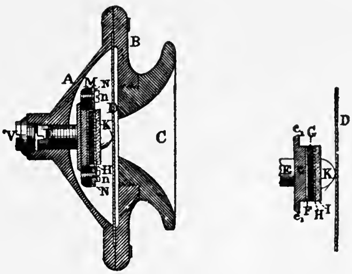


Fig. 17.—Phelps-Edison Transmitter.

shown in the small cut at the right of this figure, and is inclosed in a cup-shaped case formed of the two pieces, *A* and *B*, as shown. Secured to the front of the enlarged head, *e*, of the adjustment screw, *E*, is a thin platinum disk, *F*, against which rests a cylindrical button, *G*, of compressed lampblack. A plate of glass, *I*, carrying a hemispherical button, *K*, has attached to its rear face another platinum disk, *H*. This second platinum disk rests against the front face of the lampblack disk, *G*, and the button, *K*, presses firmly against the center of the diaphragm, *D*. The plates, *F* and *H*, form the terminals of the transmitter, and as the diaphragm, *D*, vibrates, it causes variations in the pressure, and corresponding changes in the resistance of the circuit, thus producing the desired undulations of current.

Professor David B. Hughes made a most valuable contribution tending toward the perfection of the battery transmitter. By a series of interesting experiments, he demonstrated conclusively that a loose contact between the electrodes no matter of what substance they are composed, is far preferable to a firm, strong contact. The apparatus used in one of his earlier experiments,

made in 1878, is shown in Fig. 18, and consists simply of three wire nails, of which *A* and *B* form the terminals of the circuit containing a battery and a receiving instrument. The circuit was completed by a third nail, *C*, which was laid loosely across the other two. Any vibrations in the air in the vicinity caused variations in the intimacy of contact between the nails, and corre-

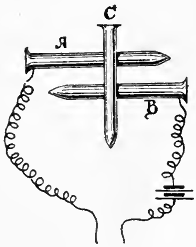


Fig. 18.—Hughes' Nail Microphone.

sponding variations in the resistance of the circuit. This was a very inefficient form of transmitter, but it demonstrated the principle of loose contact very cleverly.

It was found that carbon was, for various reasons, by far the most desirable substance for electrodes in the loose-contact transmitter, and nothing has ever been found to even approach it in efficiency.

Another form of transmitter devised by Hughes, and called by him the microphone, is shown in Fig. 19. This consists of a

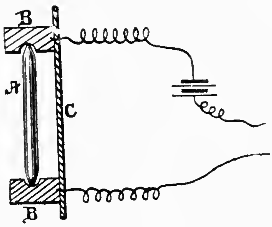


Fig. 19.—Hughes' Carbon Microphone.

small pencil of gas carbon, *A*, pointed at each end, and two blocks, *B B*, of carbon fastened to a diaphragm or sounding board, *C*. These blocks are hollowed out, as shown, in such a manner as to loosely hold between them the pencil, *A*. The blocks, *B B*, form the terminals of the circuit. This instrument, though crude in form, is of marvelous delicacy and is well termed microphone. The slightest noises in its vicinity, and even those incapable of being heard by the ear alone, produce surprising

effects in the receiving instrument. This particular form of instrument is, in fact, too delicate for ordinary use, as any jar or loud noise will cause the electrodes to break contact and produce deafening noises in the receiver. Nearly all carbon transmitters of to-day are of the loose-contact type, this having entirely superseded the first form devised by Edison, which was then supposed to depend on the actual resistance of a carbon block being changed under varying pressure.

Only one radical improvement now remains to be recorded. In 1881 Henry Hunnings devised a transmitter wherein the variable resistance medium consisted of a mass of finely divided carbon granules held between two conducting plates. His transmitter is shown in Fig. 20. Between the metal diaphragm, *A*, and a parallel conducting plate, *B*, both of which are securely mounted in a case formed by the block, *D*, and a mouthpiece, *F*, is a chamber filled with fine granules of carbon, *C*. The diaphragm, *A*, and the plate, *B*, form the terminals of the transmitter, and the current from the battery must therefore flow through the mass of granular carbon, *C*. When the diaphragm is caused to vibrate by sound waves, it is brought into more or less intimate contact with the carbon granules and causes a varying pressure between them. The resistance offered by them to the current is thus varied, and the desired undulations in the current produced. This transmitter, instead of having one or more points of variable contact, is seen to have a multitude of them. It can carry a larger current without heating, and at the same time produce greater changes in its resistance, than the forms previously devised, and no sound can cause a total break between the electrodes. These and other advantages have caused this type in one form or another to largely displace all others. Especially is this true on lines of great length.

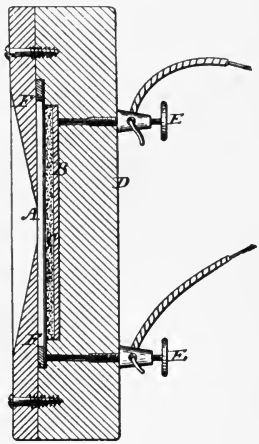


Fig. 20.—Hunning's Granular Carbon Transmitter.

Up to this time all transmitters, together with the receiver and battery, had been put directly in circuit with the line wire. With this arrangement the changes produced in the resistance by the transmitter were so small in comparison with the total resistance of the circuit, that the changes in current were also very small, and produced but little effect on the receiver. Edi-

son remedied this difficulty by using an induction coil in connection with the transmitter. The credit of this improvement, however, should be given largely to Gray, for in 1875 he had used an induction coil in connection with his harmonic telegraph transmitter, and Edison merely substituted a telephone transmitter in the circuits used by Gray.

The induction coil used then and now is made as follows: Around a core formed of a bundle of soft-iron wires is wound a few turns of comparatively heavy insulated copper wire. Outside of this, and entirely separate from it, is wound another coil, consisting of a great number of turns of fine wire, also of copper and insulated. The inner coil is called the primary, the other the secondary. In telephone work it is now almost universal practice to place the transmitter, together with the battery, in a closed circuit with the primary of the induction coil, and to place the secondary directly in circuit with the line wire and receiving instrument. This is shown in Fig. 21, in which *T*

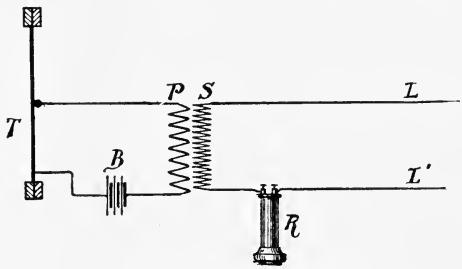


Fig. 21.—Transmitter with Induction Coil.

is a transmitter, *B* a battery, *P* and *S* the primary and secondary, respectively, of an induction coil, *L L'* the line wires, and *R* the receiving instrument. It is well to state here that the usual way of indicating the primary and secondary of an induction coil, in diagraphic representation of electrical circuits, is by an arrangement of two adjacent zigzag lines, as shown in Fig. 20. A current flowing in the primary winding of the induction coil produces a field of force in the surrounding space, and any changes caused by the transmitter in the strength of the current produce changes in the intensity of this field. As the secondary winding lies in this field, these changes will, by the laws of Faraday and Henry, cause currents to flow in the secondary winding and through the line wire to the receiving instrument. In all good induction coils the electromotive forces set up in the secondary coil bear nearly the same ratio to the changes in electromotive

force in the primary coil, as the number of turns in the secondary bears to the number of turns in the primary.

The use of the induction coil with the transmitter accomplishes two very important results: first, it enables the transmitter to operate in a circuit of very low resistance, so that the changes in the resistance produced by the transmitter bear a very large ratio to the total resistance of the circuit. This advantage is well illustrated by contrasting the two following cases:

Suppose a transmitter capable of producing a change of resistance of one ohm be placed directly in a line circuit whose total resistance is 1000 ohms; a change in the resistance of the transmitter of one ohm will then change the total resistance of the circuit one one-thousandth of its value, and the resulting change in current flowing will be but one one-thousandth of its value. On the other hand, suppose the same transmitter to be placed in a local circuit as above described, the total resistance of which circuit is five ohms; the change of one ohm in the transmitter will now produce a change of resistance of one-fifth of the total resistance of the circuit and cause a change of one-fifth of the total current flowing. It is thus seen that fluctuations in the current can be produced by a transmitter with the aid of an induction coil which are many times greater than those produced by the same transmitter without the coil.

The second advantage is that by virtue of the small number of turns in the primary winding and the large number in the secondary winding of the induction coil, the currents generated in the secondary are of a very high voltage as compared with those in the primary, thus enabling transmission to be effected over much greater length of line and over vastly higher resistances than was formerly the case.

CHAPTER III.

THE TELEPHONE RECEIVER.

To construct a receiver capable of reproducing speech is a very simple matter. In fact, nearly any electromagnet, with a comparatively light iron armature, such as is commonly used in electric bells and telegraph instruments, may be made to reproduce, with more or less distinctness, sounds uttered in the vicinity of a transmitting apparatus with which it is in circuit. It has proved more difficult, however, to construct a receiving instrument which will reproduce speech *well*, and at the same time be practically successful in everyday use.

The bar-magnet with a thin iron diaphragm in close proximity to one of its poles, used in the early experiments in telephony, has until recently been very generally adhered to throughout this country. The instrument has been made much more sensitive than were the early forms, but this result has been accomplished by better mechanical and electrical designs, and the use of better materials, and not by any departure from the original principles of its action.

Aside from actual talking efficiency, many considerations of a purely mechanical nature enter into the design of a good telephone receiver. It should be durable and capable of withstanding the rough usage to which it will necessarily be subjected by careless or ignorant users. It should be of such construction that its adjustment will not be changed by mechanical shocks or by changes in temperature. Failure to provide against this latter effect is one of the chief sources of trouble in telephone work. It should be of such external configuration as to enable it to be conveniently placed to the ear. The chamber in which the diaphragm vibrates should be small and of such shape as not to muffle the sound. The binding posts should be so securely fastened in as to prevent their becoming loose and twisting off the wires inside the receiver shell; and the construction should be so simple as to render the replacing of any damaged part an easy matter.

By far the greater number of receivers used in America are of the single-pole type; although in a few years this statement will

probably not be true. The particular form shown in Fig. 22 has proved efficient, and is now largely used by the American Bell Telephone Company. Its chief merit lies in its simplicity.

In Fig. 22, *M* is a compound bar-magnet, composed of two pairs of separately magnetized steel bars arranged with like poles together. Between the pairs of bars is clamped a soft-iron pole-piece, *P*, at one end, and a similarly shaped iron block, *Q*, at the other end. These parts are firmly bound together by the two screws, *S S*. On the end of the pole-piece is slipped a coil of wire, *G*. This coil is usually wound with two parallel No. 38 B. & S. silk-insulated copper wires, and has a total resistance of about 75 ohms.

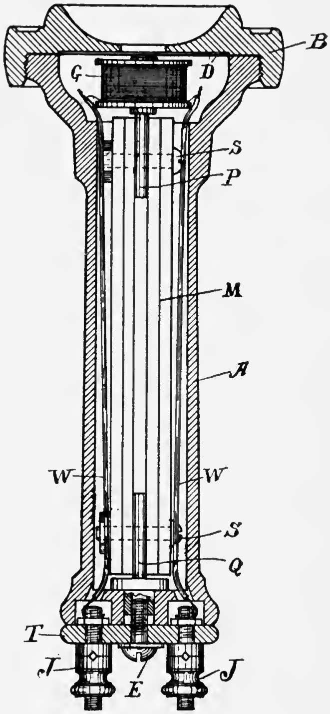


Fig. 22.—Bell Single-Pole Receiver.

The magnet is incased in a shell of hard rubber, composed of two pieces, *A* and *B*, which screw together and clamp between them the diaphragm, *D*, of thin sheet iron. The piece, *B*, is hollowed out as shown, to form a convenient earpiece. A tailpiece, *T*, carrying two binding posts, *J J*, fits over the end of the case opposite the earpiece, *B*, and is held in place by a screw, *E*. This screw engages a threaded hole in the block, *Q*, and serves not only to hold the tail-piece in place, but to bind the magnet securely to the shell. Soldered to the binding posts are heavy leading-in wires, *W W*, which pass along the sides of the magnet and are soldered to the respective terminals of the fine wire forming the coil.

The diaphragm of this instrument is about $\frac{1}{100}''$ in thickness and $2\frac{1}{4}''$ in diameter. The diameter of the free portion is $1\frac{3}{4}''$.

In some single-pole receivers the old style of magnet, consisting of a single cylindrical bar of steel, is still used instead of the compound magnet formed of several separately magnetized bars, but with generally inferior results, owing to its weaker and less permanent magnetic field.

In bipolar receivers, which are now coming into general use,

the object is to strengthen the field in which the diaphragm vibrates, by presenting both magnet poles to the diaphragm. The length of the path of the lines of force through the air is thus greatly shortened, and the field of force is concentrated at the point where it will be most effective.

One form of bipolar receiver is shown in Fig. 23, which illustrates the receiver manufactured until recent date by one of the large independent companies. The shell, *A*, and ear-piece, *B*, are of a

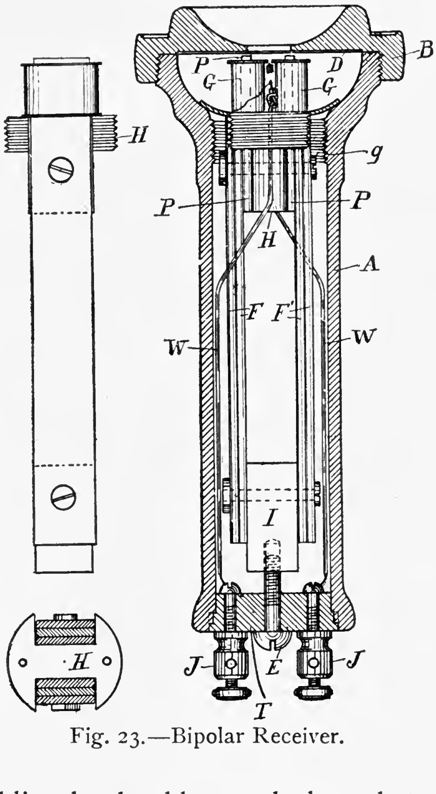


Fig. 23.—Bipolar Receiver.

material resembling hard rubber, and clamp between them the soft-iron diaphragm, *D*, as in the instrument described above.

The magnet consists of two pairs of separately magnetized steel bars, *F F* and *F'F'*, the separate bars in each pair being laid with like poles together, so that each pair forms in itself a compound bar-magnet. These two compound bar-magnets are so laid together that the north pole of one is opposite the south pole of the other. The two pairs of bars are held apart at one end by the adjustment block, *H*, made of the same material as the shell,

and at the other end by the soft-iron block, *I*. On each side of the block, *H*, and between it and the pairs of bar-magnets, are the soft-iron pole-pieces, *P P*, on which are wound the coils *G G*, having a resistance of 50 ohms each. These coils are wound with No. 36 B. & S. silk-insulated wire and are connected in series, so that the total resistance of the receiver is 100 ohms.

The block, *H*, has two segmental flanges projecting out beyond the sides of the magnet bars. These flanges are screw-threaded on their circumferential surfaces so as to engage a thread, *g*, on the inner surface of the shell, *A*. The magnet may thus be adjusted toward or from the diaphragm by turning it in the shell, *A*.

A tail-piece, *T*, of hard rubber is so shouldered as to fit into the small end of the receiver shell, and is prevented from turning in its place by small lugs fitting into notches in the shell. A screw, *E*, extends through the tail-piece and clamps the magnet into any position to which it has been adjusted. To the binding posts, *J J*, are soldered heavy leading-in wires, *W W*, which pass through holes in the adjustment block, *H*, and are soldered to the terminals of the fine magnet wire. These heavy wires, *W W*, are firmly knotted after passing through the block, *H*, in order to prevent any mechanical strain coming on the hair-like wires of the magnet coils when the tail-piece is removed. Sufficient slack is left in the leading-in wires to allow the removal of the tail-piece a short distance, to give access to the end of the magnet for purposes of adjustment.

In many forms of receiving instruments much trouble is experienced in keeping permanent the adjustment between the magnet and the diaphragm. This is due to the fact that steel and hard rubber differ widely as to their amounts of expansion or contraction under changes in temperature. In instruments where the magnet is rigidly secured to the shell only at a point at considerable distance from the diaphragm, the unequal expansion or contraction of the magnet and the shell causes the distance between the pole-piece and the diaphragm to vary with every change in temperature. A sudden change will thus often render a receiver inoperative.

This defect is seen to exist without any attempt at a remedy in the single-pole receiver shown in Fig. 22. The point of support of the magnet is as far removed from the diaphragm as possible, being at the screw, *E*, and therefore the full benefit (which is of course negative) of all the differences in contraction and expansion between the hard rubber and the steel is obtained.

In the receiver shown in Fig. 23 an attempt was made to remedy this defect by securing the magnet to the shell at a point close to the diaphragm, so that the differences in expansion and contraction between the shell and magnet will be reduced to a minimum. This, however, in this particular case introduced a defect quite as serious, because the shell was also bound to the magnet by the screw, *E*. The contraction and expansion thus tended to loosen the screw-thread on the block, *H*, making frequent readjustment necessary. Moreover, a good screw-driver in the hands of an ordinary repair man or of a subscriber often subjects the screw-thread on block, *H*, to such a strain as to strip the thread, thus rendering the receiver useless.

Several important lessons may be and have been learned from the behavior of these two forms of receiver in actual and long-continued service:

First: It is poor construction to secure the magnet in the shell at the end farthest from the diaphragm.

Second: It is also poor construction to secure it rigidly near the diaphragm and also at the opposite end.

Third: It is extremely poor construction to use any of the materials imitating hard rubber in vital portions of the instrument. These materials, so far produced, are without exception subject to some or all of the following faults to a greater extent than hard rubber, viz.: They are not sufficiently tough, and are usually very brittle. They absorb moisture. They soften when exposed to heat, and gradually give way under pressure, causing them to retain a permanent set when again cooled. They are capable of having threads molded upon them, and as a rule these molded threads do not fit. Threads in hard rubber are cut, and may therefore be as accurate as desired. They are liable to have seams or "cold shuts" formed in molding which will cause cracks and fractures; and lastly: They are not as good insulating materials as hard rubber. Some of these materials may not possess all of these objections, but all possess some of them. Hard rubber therefore is, so far as materials are at present developed, the only thing to use in the insulating portions of receiver shells.

A way of obviating the expansion and contraction difficulty, used largely in European countries and to an increasing extent in this country, is to construct the shell holding the diaphragm of some metal having nearly the same coefficient of expansion as the steel magnets.

Fig. 24 shows one of the early forms of bipolar receivers.

This was devised in 1881 by Clement Ader of Paris, France, and is with some modifications largely used in France and other European countries to-day. This embodies the results of one of the few successful attempts at increasing the electrical efficiency of the telephone receiver. The magnet, *B*, is ring-shaped, and has fastened to its poles two L-shaped pole-pieces carrying coils, *C C*. The box, *R*, inclosing the pole-pieces and coils is of brass and is secured to the magnet by screws, *E E*. It is screw-threaded at *G*, so as to engage a corresponding screw-thread on the inner surface of the cap, *S*, which has a flaring portion, *H*,

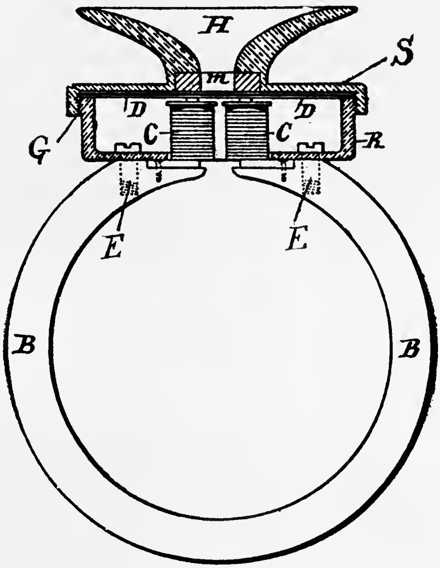


Fig. 24.—Ader Bipolar Receiver.

forming an ear-piece. The diaphragm, *D*, is clamped between the pieces, *R* and *S*, as in the American instruments described above.

Surrounding the opening, leading from the diaphragm to the ear-piece, is a ring, *m*, of soft iron, and in this ring lies the chief point of Ader's invention. The additional mass of iron placed near the poles of the magnet affords a more ready path for the lines of force, and their number is thus increased. The diaphragm, therefore, moves in a stronger field of force, and the power of the receiver is said to be correspondingly augmented. Practice in this country has not, however, shown any perceptible gain of efficiency by the use of this ring.

Fig. 25 shows the form of receiver now manufactured by the Western Telephone Construction Company of Chicago. In this the shell is of hard rubber, composed of three pieces; the diaphragm being clamped between the shell and ear-piece in the ordinary manner. The magnet is of horseshoe form and carries a block of brass grooved on each side to partially inclose the magnet limbs. The lower portion of this block is screw-threaded, as shown, so as to engage the corresponding thread turned in the receiver shell. The upper flange on the block rests on a corresponding flange on the interior of the shell when the magnet is screwed home. The pole-pieces are secured to the outside of the magnets by a bolt passing entirely through the brass block, each limb of the magnet, and each pole-piece. This bolt is provided with a nut at each end, so that either pole-piece may be taken off without removing the other. The heads of the magnet

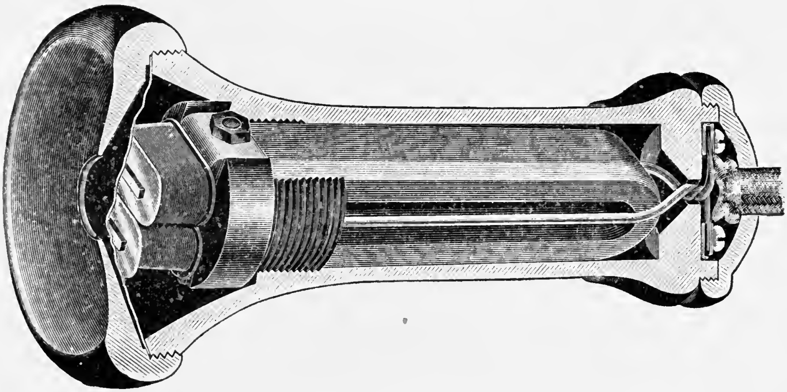


Fig. 25.—Western Telephone Construction Co.'s Receiver.

spools are of brass pressed into position on the pole-pieces. After being insulated, the spools so formed are wound in a machine having a special chuck for holding the pole-pieces. The two coils are for standard work, wound to a resistance of 50 ohms each with No. 36 silk-insulated wire and connected in series, thus making the total resistance of the receiver 100 ohms.

The novelty in this receiver is in the method of attaching the receiver cord to the terminals leading from the coils. These terminals, as shown, are composed of heavily insulated wire passing through the brass block into the coil chamber. The other ends of these wires are twisted together and pass through a central opening, where each is soldered to a connector held in place against the shell by a small machine screw. The cord is provided

with similar connectors, which may be slipped under the screw-heads, thus completing the circuit between the cord and the wires of the receiver. The connection of the cord is, of course, made before the tail-cap is screwed in place. An enlargement in the covering of the cord effectually prevents any strain ever coming on the cord terminals when the receiver is dropped. Another feature secured by this construction is that no metal parts are exposed on the outside of the shell, thus insuring immunity from electric shocks while handling the receiver, this being considered very desirable by some.

This receiver, except for the method of connecting the cord, which was designed by the writer, is almost identical with that used by The American Bell Telephone Co., in their long-distance work, and also in most of their common-battery exchanges. In the Bell receiver the tail-cap is not provided, and instead two flanged binding posts are screwed directly to the hard rubber from the outside. To these binding posts the ordinary receiver cord is attached in the usual way, and the wires leading from the receiver magnets pass through the shell and are soldered to an extension of the binding posts. These forms of receiver are very efficient, very easily adjusted, and subject to little or no trouble from the source of expansion and contraction, it being seen that the magnet is supported at a point near the diaphragm without being bound to the shell at any other point.

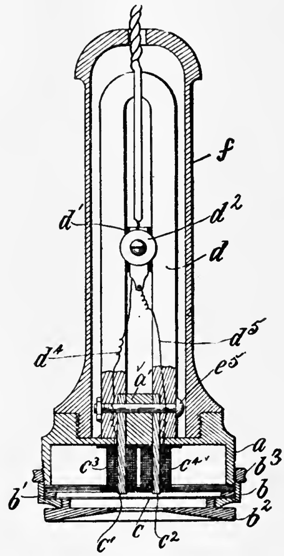


Fig. 26.—Stromberg-Carlson Receiver.

The Stromberg-Carlson receiver is a very powerful one, and has stood the test of time well. It is shown in Fig. 26, in which *a* is a casing of brass, forming a framework upon which all other parts of the instrument are supported. This is screw-threaded on its outer surface to receive the internally screw-threaded cap, *b*, and lock-ring, b^3. One unique feature of this receiver is the method of supporting the diaphragm, which is held in place in the cap, *b*, by the clamping ring b'.

Upon the cap, *b*, is screwed an ear-piece, b^2. The lock-ring, b^3, is adapted to be screwed against the cap, *b*, to lock it in any adjusted

position. Upon the rear of the casing is provided a projection, a', against the faces of which rest the soft-iron cores, c^1 c^3, which extend through the bottom of the casing and carry upon their ends the telephone coils, c^3 c^4. The ends of the permanent magnet, *d*, rest upon the cores, c^1 c^2, and a screw or bolt, e^5, passes through the ends of the magnet, the cores, and the projection, to maintain them in position. The ends of the magnet, *d*, are cut away as shown to permit the cores to be set flush with the inner faces of the magnet.

Between the limbs of the magnet, *d*, is provided a block, d', of

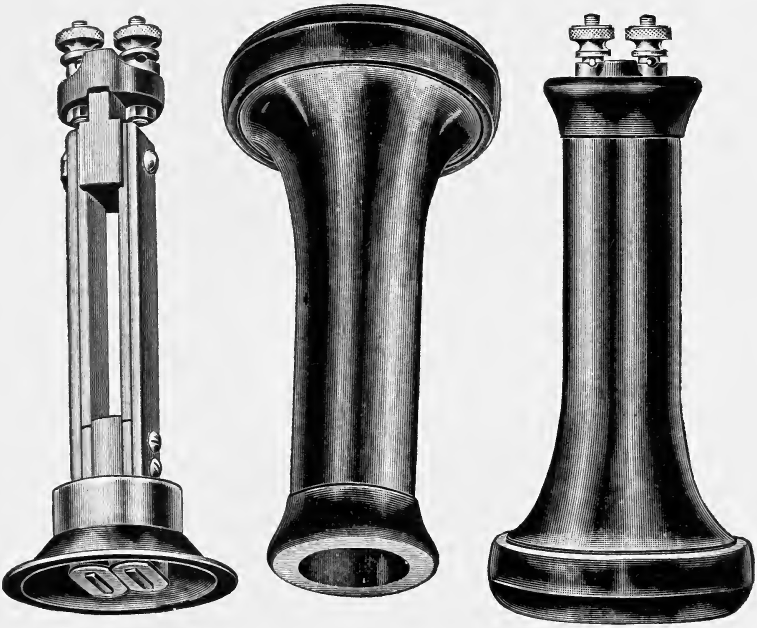


Fig. 27.—American Electric Telephone Co.'s Receiver.

fiber upon which are mounted two binding posts, d^2, the binding posts being connected to the coils, c^3 c^4, by heavy insulated wires, d^4 d^5. To the binding posts, d^2, are also attached the ends of the receiver cord. Upon the rear of the casing, *a*, is provided a threaded flange upon which the insulating casing, *f*, is screwed, this latter being provided with an opening at the end through which the receiver cord passes.

The magnet, *d*, is mounted rigidly upon the casing, *a*, the casing, *f*, being entirely independent so that it may be removed by unscrewing. The diaphragm support or cap, *b*, may be raised or lowered to adjust the diaphragm relatively to the magnet

cores, c' c^2, the ring, b^3, serving to lock the diaphragm in its adjusted position.

This receiver does away entirely with the troublesome effects due to expansion or contraction. The insulating casing forms a handle and serves as a protection to the cord terminals, but forms no part of the working structure itself.

In Fig. 27 is shown the bipolar receiver of the American Electric Telephone Co. The permanent magnet is formed of two pieces which clamp between them, at the end farthest from the diaphragm, a cast-iron block on which is mounted a hard-rubber disk carrying the binding posts. This block, therefore, serves the double purpose of completing the magnetic circuit between the ends of the magnets and of a support for the binding posts and connections. The lower ends of the magnets carry a screw-threaded disk upon which is screwed the metal cup containing the coils and against which the diaphragm rests. Upon this block are also mounted the straight pole-pieces carrying coils similar to those shown in Fig. 23. The cup forming the chamber for the coils is of pressed brass, nickel-plated and screw-threaded to engage the threaded disk carried by the magnet. Over this entire structure is slipped the case of hard rubber, the diaphragm being clamped between the earpiece and the brass cup. In this receiver, adjustment is obtained by turning the cup on the magnet, the screw-threads producing a longitudinal movement of the latter in respect to the former, thus moving the pole-pieces toward or from the diaphragm, according to the direction of the rotation. After the desired adjustment has been obtained, the cup may be clamped in the position desired by two screws projecting through flanges carried by the circular disks of the magnets and extending into the interior of the cup. These screws, when set, engage the bottom of the cup in such manner as to hold it from turning.

A single-pole receiver, manufactured by the Holtzer-Cabot Electric Co., and embodying features of decided merit, is shown in Fig. 28. In this the magnet is composed of four bars of steel separately magnetized and clamping between them at one end an iron block drilled and tapped to receive the screw passing through the end of the shell. A pole-piece flanged, and screw-threaded as shown, is clamped between the other ends of the magnets. The cup for inclosing the coil and carrying the diaphragm is of brass, having a hole through its center, screw-threaded to engage the threaded portion of the pole-piece. When screwed in position, the flat portion of the cup abuts the

flange on the pole-piece, thus binding the two rigidly together. The ear-piece is of hard rubber, as usual, and screws to the brass cap, thus holding the diaphragm in position. The inclosing shell of hard rubber slips over the magnet as shown, and carries the binding posts, which are connected by heavy leading-in wires to the receiver coil. No form of adjustment is provided for this instrument, and this, by the way, is a feature

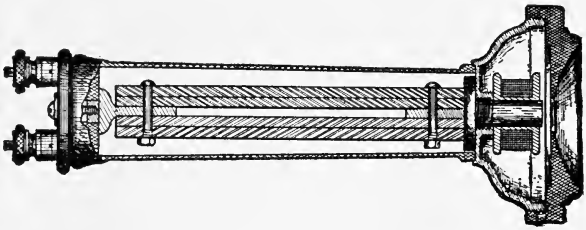


Fig. 28.--Holtzer-Cabot Receiver.

which is meeting with considerable favor and is being adopted by several manufacturing companies. Great care is taken by the manufacturers to adjust the instrument properly before it leaves the factory, after which, with an instrument properly constructed, no need for adjustment should exist.

Still another form of receiver, and one of the non-adjustable type, is shown in Fig. 29: this is manufactured by the Ericsson Co. of Sweden, and is being imported into this country to a considerable extent. This is of the bipolar type presenting to the diaphragm two coils and two pole-pieces very similar in shape to those shown in Fig. 23. The magnets are secured to the metal cup by means of two screws shown in the

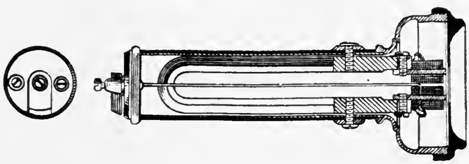


Fig. 29.—Ericsson Receiver.

figure, each extending transversely through the case and into the magnets. The holes in the case through which these screws project are slotted so that a certain amount of adjustment can be obtained if it is absolutely necessary, although the idea of the manufacturers is to bind it so tightly that no adjustment will ever be needed. The inclosing tube for the magnets is of brass covered by a thin layer of insulating material, usually hard rubber,

but sometimes of leather. This tube is also held in position by the screws before mentioned. A piece of hard rubber projects between the two binding posts of the instrument as shown, the object of this being to prevent the tips of the receiver cords from twisting the posts in their sockets until they touch each other, thus short-circuiting the instrument. This same feature will be noticed in the receiver shown in Fig. 27. This receiver is extremely well made, very handsome in appearance and very efficient, and probably would have come into very large use were it not for its high cost.

In the receivers shown in Figs. 26, 27, 28, and 29 the evil effects due to contraction and expansion of the various parts are avoided by the use of metal cups for securing the diaphragm. This method, as before stated, is coming into increasing favor in this country, although it had long been used in Europe. The first receiver built with a metal cup which came into anything like extensive use in this country, was designed by Messrs. Stromberg & Carlson, and is of substantially the same form as that shown in Fig. 26. The advocates of the hard-rubber shell claim that the exposed metal portion of the cup is a source of great danger in lightning storms, or in case the line has become crossed with some high-potential wire. This idea has been carried to its extreme in Fig. 25, where not even the binding posts are exposed. When it is remembered, however, that many other parts of a telephone, such as the line binding posts, generator crank, magneto-gongs, transmitter, and transmitter arm, have exposed metal surfaces some of which are directly in connection with the line, it is somewhat doubtful whether this objection is a very valid one.

The diaphragms used for receivers are made of very soft thin sheet iron; the ferrotype plate formerly used for tin-types in photography being as good material as can be found for this purpose. Some companies, however, notably the Ericsson, the Stromberg & Carlson, and the American, are using tinned diaphragms, which give equally good results.

The diaphragms for the various receivers here described vary from 2 to $2\frac{5}{16}$ inches in diameter, the free portions—that is, the portion not clamped by the supports—ranging from $1\frac{3}{4}$ to $2\frac{3}{16}$ inches. The usual thickness is from .009 to .011 of an inch. The thickness of a diaphragm, to produce the best results with the given receiver, must be obtained by experiment, as it depends on the diameter of the portion free to vibrate, and also on the strength of the magnetic field due to the permanent magnet. It has been

shown that with a very thin diaphragm and a very powerful magnet the iron in the diaphragm becomes saturated so that it is not responsive to changes in the strength of the existing field. Of course, the thicker the diaphragm is the less likely is this to occur. Many manufacturers aim at making the magnets of their receivers extremely powerful, but it is very doubtful if much or any increased efficiency results therefrom.

The question of receiver cords is one of a good deal of importance, as a faulty cord is one of the most prolific sources of trouble of any part of a telephone instrument. If the conductors in a cord are not properly insulated, so that they may come into contact, or if a break occurs in one of the conductors, the instrument will be short-circuited in the one case, or the circuit left open in the other. In either event the receiver is rendered completely useless. These faults are frequently very elusive, as a slight movement of the cord may cause them to appear or disappear. The conductors in receiver cords are usually composed of tinsel woven or twisted into strands, and a few strands of fine cop-

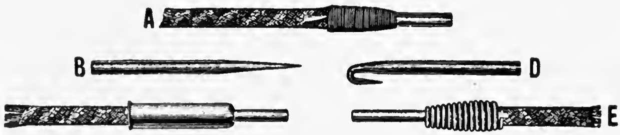


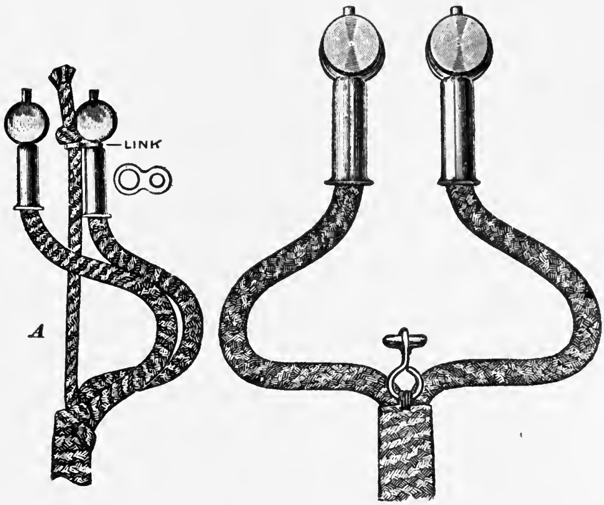
Fig. 30.—Details of Receiver Cord Tip.

per wire are frequently added to give greater strength. These tinsel conductors are then tightly braided, or wrapped with cotton, silk, or linen, sometimes in several layers, and in some cases inclosed in a spiral wrapping of spring-brass wire which incloses each conductor of a cord separately, these two spirals being laid side by side and braided over with the familiar colored worsted braid. It is probably better, in putting on the first covering over the tinsel, to make it a wrapping instead of a braid, as the former tends to bind the tinsel strands together more securely than the latter, thus preventing any short ends of the conductor from piercing the covering and short-circuiting the cord.

The question of tips for receiver cords is one which has received much attention, as faulty tips are a great source of trouble. These are necessarily subject to rather rough usage, as it frequently happens that a receiver is dropped, thus allowing a heavy strain to come on the cords, which is usually most severe where the tip joins the cord proper. The connection shown in Fig. 30 is one which has become very popular.

This is formed by inserting a needle or pin, *B*, of No. 14 brass wire tapered to a long point, into the hollow of a braided tinsel cord or spiral spring, as the case may be, for one-half inch, when the end is passed out through the conductor and covering and bent backward, forming a hook, as shown at *D* and *A*, thus combining the strength of the conductor and covering. Before the pin is put in, the conductor is bared for a short distance and, after the pin is inserted, is wound with fine wire and soldered. The tip is then finished with a spiral of white wire as shown at *E*, or with a shell as shown at *C*.

In order to prevent an undue strain on the conductors when receiver is dropped, it is best to have the cord provided at each



Figs. 31. and 32.—Supporting Loop and Hook for Receiver Cord.

end with an auxiliary loop, *A*, as in Fig. 31. This loop is usually a continuation of the braiding of the cord, and may be fastened to an eyelet in the receiver, or to a small link on one of the binding posts. Another way of accomplishing this same result is by means of a hook (Fig. 32) sewed to the braiding, just at the fork of the cord, which may be closed by a pair of pliers around a screw-eye or one of the screws in the binding post.

CHAPTER IV.

CARBON TRANSMITTERS.

MANY vain attempts have been made to discover a satisfactory substitute for carbon as the variable resistance medium in telephone transmitters, the patents on the use of carbon electrodes having, until a few years ago, formed one of the mainstays of the American Bell Telephone Company's great monopoly.

The theory of the action of carbon in the transmitter has been the subject of much discussion. As previously pointed out, any motion of the diaphragm increasing the pressure between the electrodes lowers the resistance between them, thus allowing the passage of a greater current. A decrease of pressure produces the opposite result.

Four different explanations for this action have been put forth, and are as follows:

First, that the electrical resistance of the carbon itself is caused to vary by the changes in pressure.

Second, that a film of air or gas exists between the electrodes, and that the thickness of this film is varied by the changes in pressure, thus varying the resistance. This theory is apparently still adhered to by Mr. Berliner.*

Third, that the peculiar property possessed by carbon of lowering its resistance with increased temperature is in the following way accountable for the action, in part at least: that an increase of current (due to increased pressure and diminished resistance between the electrodes) causes a slight heating at the point of contact; that this heating causes a still further diminution of resistance with an additional increase of current; and that conversely a momentary decrease of current causes a decrease of temperature with a corresponding additional increase of resistance and diminution of current.

Fourth, that change in resistance is due to the variation in the area of contact between the electrodes—that is, the variation in the number of molecules in actual contact. This change in area is perfectly apparent in the liquid transmitter of Gray, and in the

* "Microphonic Telephonic Action," by Émile Berliner, *American Electrician*, March, 1897.

case of solid electrodes may be well illustrated by the following well-known experiment:

If a billiard ball be gently pressed on a plain marble slab coated with graphite, the area of contact of the ball with the slab will be indicated by a small dot of graphite on the ball. If, now, the ball be dropped from a considerable height, it will be noticed that the spot of graphite on the ball is much larger, showing that the ball has flattened out to a considerable extent, owing to the greater pressure exerted. This demonstrates clearly the variation in area of contact between two bodies, due to variations of pressure between them. Of course, if the two bodies are conductors of electricity, the resistance between them will vary inversely and the current directly as the area of contact.

It seems most probable to the writer that of the above explanations, the fourth is the true one, and that none of the others aid in any perceptible degree in producing desirable effects in the microphone.

As to the first explanation, that the resistance of the carbon itself changes under pressure, experiments have been made with long carbon rods; and with measuring instruments of ordinary sensibility no difference whatever could be detected in the resistance of a rod when the pressure on it was varied from zero up to the crushing point, care being taken that all contacts in circuit were not subjected to the change in pressure.

As to the layer of air theory, Professor Fessenden has thrown some light upon it,* by showing that if the layer of air were in the ordinary gaseous state, its resistance would be almost infinite, while if it existed in some peculiar condensed state of which we know little, but in which air might be conceived to be a conductor, then the law of change of resistance between the electrodes would be different from what it has actually been found to be. On the other hand, the curves plotted with resistances as ordinates and with distances as abscissæ have been found by Professor Fessenden and by Messrs. Ross and Dougherty to exactly agree with the form obtained from theoretical considerations on the basis that the change in resistance is due to area of surface contact alone.

As to the third explanation, it may be said that the very fact that the increase of current is needed to cause the rise of temperature seems to preclude the supposition that the rise of temperature should cause the diminution of resistance with its corresponding

* "Microphonic Telephonic Action," by Professor R. A. Fessenden, *American Electrician*, May, 1897.

increase of current in time to do any good. The heating effects in carbon are comparatively slow, and it would seem that the changes in temperature would lag slightly behind the changes in current producing them, in such a manner as to be detrimental to telephone transmission.

This property of carbon, of lowering its resistance with increased temperature, is, however, important in that when the transmitter becomes warm from constant use its resistance as a whole is decreased. When the transmitter is heated the total resistance of the circuit is lowered, and the changes in resistance produced by the sound waves therefore bear a greater ratio to this total resistance with corresponding increase of efficiency.

It is certainly most fortunate that in one substance—carbon—should be found all of the qualifications which make it particularly desirable for microphonic work. It produces the change in resistance with changes in surface contact, all things considered, better than any other known substance, possesses the desirable

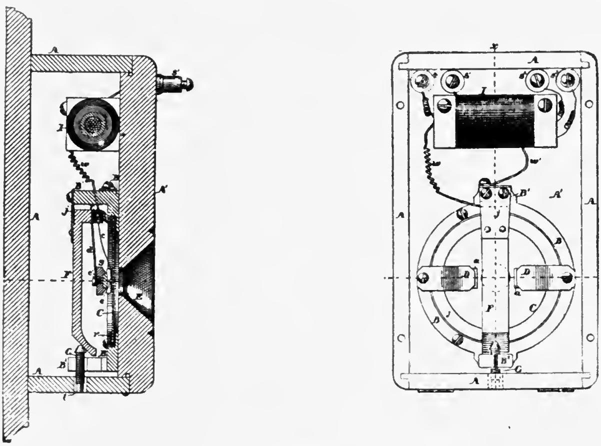


Fig. 33.—The Blake Transmitter.

property of lowering its resistance when heated, and is elastic, non-corrosive, non-fusible, cheap, and easily worked.

The form of transmitter almost universally used in this country up to within a few years ago, and still largely used, is that devised by Francis Blake of Boston. This instrument is shown in Fig. 33, in which *B* represents a metal ring or frame for holding the mechanism of the instrument. It is screwed to the cover, *A'*, of the box *A*, and has two diametrically opposed lugs, *B' B*². On this ring is mounted the diaphragm, *C*, of rather heavy sheet

iron, supported in a rubber ring, *r*, stretched around its edge, and is held in place by two damping springs, *D D*, each bearing on a small block of soft rubber, *a*, resting on the diaphragm at a point near its center. The object of these damping springs is to prevent too great an amplitude of vibration of the diaphragm, and also to keep it from vibrating in separate parts instead of as a unit.

Opposite the center of the diaphragm is the orifice, *E*, in the cover, *A'*, so hollowed out as to form a mouthpiece. The adjusting lever, *F*, is attached to the spring, *j*, secured to the lug, *B'*, of the ring, *B*. The lower end of this lever rests upon an adjusting screw, *G*, in the lug, B^2, which is drilled and slotted as shown to prevent the screw from working loose. On the back of the diaphragm and at its center is placed the front electrode, consisting of a small bar, *e*, of platinum; one end of the bar rests against the diaphragm, while the other end is brought to a blunt point and is in contact with the back electrode, *e'*. The electrode, *e*, is supported independently upon a light spring, *c*, mounted on the lever, *F*, but insulated from it. This spring tends to press away from the diaphragm and toward the back electrode. The back electrode is formed of a block of carbon, *e'*, set into a brass block, *g*, of considerable weight, mounted on a spring, *d*, supported on the adjusting lever, *F*. This spring, *d*, has a tension in the opposite direction to that of the spring, *c*, and being stronger than the latter it keeps the electrode, *e*, in contact with the diaphragm.

It is seen that instead of having one of the electrodes held in fixed position while the other is pressed against it with greater or less force by the vibration of the diaphragm with which it is connected, both electrodes are supported in such manner as to move freely with the diaphragm, but the outer electrode is so weighted that its inertia will offer enough resistance to the slight and rapid vibrations of the diaphragm to give a varying pressure between the electrodes and consequent changes of the resistance of the circuit. By this means the initial pressure between the two electrodes will not be affected by changes of temperature, and the adjustment will therefore be more nearly permanent.

This transmitter is very delicate, and transmits the quality of the voice in a manner unexcelled by others. It is, however, lacking in power, especially when compared with instruments of later design. Besides this, it has a tendency to rattle or break contact when acted on by loud noises.

Fig. 34 illustrates the Crossley transmitter, introduced into Europe early in 1879. This well illustrates the class very

appropriately termed "multiple-electrode." Transmitters devised by Johnson, Gower, Ader, D'Arsonval, Turnbull, and many others are of this type, and differ merely in the arrangement and number of electrodes. They give much more powerful results than the transmitters having a single pair of electrodes, but most of them are subject to the grave defect of breaking the circuit entirely when subjected to loud noises.

In this figure, *J* represents a diaphragm formed of a thin piece of pine board about $\frac{1}{8}''$ thick and mounted on a supporting ring,

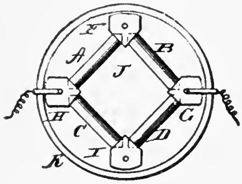


Fig. 34.—The Crossley Transmitter.

K. Fastened to this diaphragm are four carbon blocks, *F G H* and *I*, in the relative positions shown. These are hollowed out to receive the conical ends of the carbon pencils, *A B C* and *D*, which are supported loosely between them. The blocks, *H* and *G*, form the terminals of the transmitter. The current divides at the block, *H*, and passes through the pencils, *A* and *C*, in multiple to the blocks, *F* and *I*, and thence through the pencils, *B* and *D*, to the other electrode, *G*. Vibrations of the diaphragm cause variations in the intimacy of contact between the eight points of

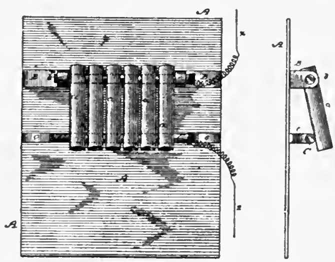


Fig. 35.—The Turnbull Transmitter.

support of the four rods, and thus produce the desired fluctuations in resistance. It is seen that this is merely a modification of the Hughes microphone, the principles being the same, but the multiple contact allows a greater current to pass through the transmitter, and at the same time produce greater changes in this current than in the original form, where a single pencil was used. Moreover, the liability of "rattling" is greatly reduced.

Fig. 35 shows the Turnbull transmitter, which has been used to a considerable extent in this country, even until recently. In this figure, *A* is the diaphragm of thin wood, on the back of which is mounted the bracket, *B*. Pivoted on a rod, *b*, carried by this bracket, are several carbon rods or pendants, *a*, which rest at their lower end against a carbon rod, *c*, carried on a bracket, *C*, also mounted on the diaphragm. The rods, *b* and *C*, form the terminals of the transmitter, and the current passes from one of them through the carbon pendants in multiple to the other. The variable resistance contact is mainly between the rod, *C*, and the pendants, *a*, although by making the rod, *b*, of carbon also an additional effect is obtained between it and the pendants.

Fig. 36 shows still another form of the multiple-electrode transmitter, using carbon balls instead of pencils or pendants. *A* represents the vibratory diaphragm of carbon; *B* a plate of carbon having a number of cylindrical cavities, *t t*, upon one side. Fitting loosely in each cavity is a ball of carbon. The

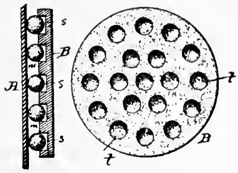


Fig. 36.—The Clamond Transmitter.

depth of the cavities is a little less than half the diameter of the balls, and the diaphragm is so placed in front of the plate that the balls, following their tendency to roll out of the cavities, will rest against its inner surface and also upon the edges of the cavities. Many other forms of instruments have been devised using one or more balls held in various positions between carbon plates. Some are used to-day, but all the transmitters so far described are being rapidly replaced by the Hunnings form of instrument, which, as has already been stated, uses carbon "dust" or granules for the variable resistance medium.

Among the earlier forms of the granular transmitter is a very efficient one designed by Émile Berliner, and called the "Berliner Universal." In this the diaphragm, *D* (Fig. 37), is of carbon, and is mounted horizontally in a case formed of the two pieces, *A* and *B*, of hard rubber, a brass ring, *R*, being clamped above it to insure good electrical contact. Secured to the enlarged head, *f*, of the screw, *s*, mounted on the block, *B*, is a cylindrical block of carbon, on the lower face of which are

turned several concentric V-shaped grooves. The points formed between these grooves almost touch the diaphragm. The finely divided carbon, *c*, rests on the diaphragm, and is confined in the space between it and the carbon block by a felt ring, *F*, which

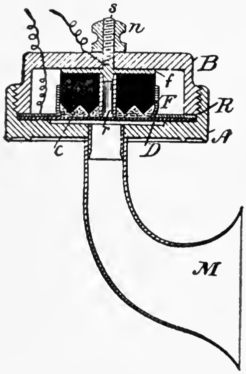


Fig. 37.—The Berliner Universal Transmitter.

surrounds the latter and bears lightly against the diaphragm. To the center of the back plate a soft-rubber tube, *r*, is fixed which is of sufficient length to make contact with the diaphragm, its function being that of a damper to the vibrations of the diaphragm. The mouthpiece, *M*, is so curved as to conduct the sound waves against the center of the diaphragm. This trans-

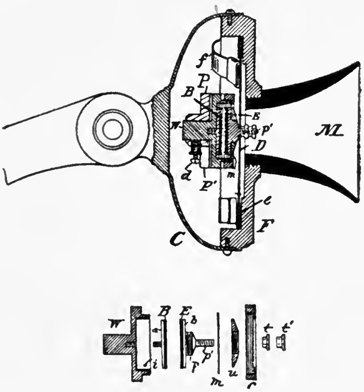


Fig. 38.—Details of Solid Back Transmitter.

mitter was used to a considerable extent by the American Bell Telephone Company, and has now been entirely replaced for long distance work by the White transmitter.

The White, or "solid back," transmitter, as it is called, is

shown in Figs. 38 and 39, the latter giving a clear idea of the construction of the working parts of the transmitter, the back casing being removed. The upper portion of Fig. 38 shows the section of the complete instrument. The sections of Figs. 38 and 39 are taken on planes at right angles to each other. The separate parts of the "resistance button" of the instrument are shown in the small cut at the bottom of Fig. 38. This instrument has proven remarkably successful in practice, it being able to stand a very heavy current without undue heating. Besides this, the tendency of the granules to settle down in a compact mass, commonly called "packing," is greatly diminished.

F is of cast brass turned to form the front piece of the transmitter case, and is held, as shown, in the hollow shell, *C*, the two pieces forming a complete metallic casing for the working parts of the instrument. The sound-receiving diaphragm, *D*, of alu-

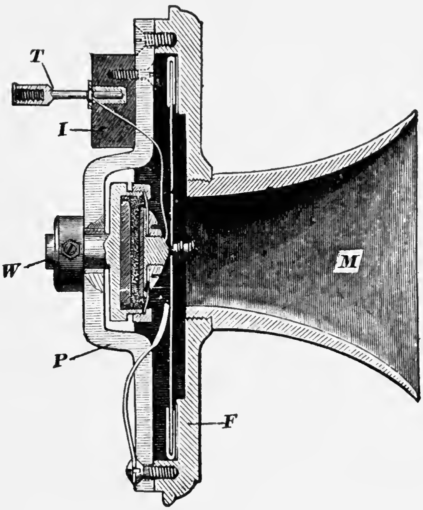


Fig. 39.—Sectional View Solid Back Transmitter.

minum, is encased in a soft-rubber ring, *e*, held in place by two damping springs, *f f*, as in the Blake transmitter. *W* is a heavy metallic block hollowed out, as shown, to form a casing for the electrodes. The inner circumferential walls of this block are lined with a strip of paper, *i*. This block is mounted, as shown, on a supporting bracket, *P*, secured at its ends to the front casting, *F*. The back electrode, *B*, of carbon is secured to the face of the metallic piece, *a*, which is screw-threaded into the block, *W*. *E* is the front electrode, also of carbon, carried on the face

of the metallic piece, *b*. On the enlarged screw-threaded portion, *p*, of the piece, *b*, is slipped a mica washer, *m*, held in place by the nut, *u*. This washer is of sufficient diameter to completely cover the cavity in the block, *W*, when the electrode is in place. After the required amount of granular carbon has been put into the cavity, and the front electrode put in position, the cap, *c*, is screwed in its place on the block, *W*, as shown, and binds the mica washer, *m*, firmly against the face of the block, *B*, thus confining the granules in their place. The electrodes are of somewhat less diameter than the paper-lined interior of the block, *W*, so that there is a considerable space around the periphery of the former, which is filled with carbon granules. This prevents the binding of the free electrode against the edge of its containing chamber, and also allows room for the granules directly between the electrodes to expand when heated by the passage of current. The screw-threaded portion, *p'*, of the piece, *b*, passes through a hole in the center of the diaphragm, and is clamped firmly in place by the nuts, *t t'*. *M* is the mouthpiece of hard rubber, screw-threaded in an opening in the front block, *F*. Any vibration of the diaphragm is transmitted directly to the front electrode, *E*, which is allowed to vibrate by the elasticity of the mica washer, *m*. The back electrode is, of course stationary, being firmly held by the bracket, *P*.

The back electrode is in metallic connection with the frame of the instrument, which forms one terminal. The other terminal, *T*, is mounted on an insulating block, *I*, and is connected by a flexible wire with the front electrode, *E*. This construction is best shown in Fig. 39.

This transmitter is now used on all of the long-distance lines of the Bell Company, and has given excellent service. It was formerly always used with three Fuller cells in series, but the tendency is now to use but two.

The following data concerning the dimensions and material used in this instrument will, it is believed, be found of much interest:

Diaphragm—aluminum, $2\frac{1}{2}''$ diameter and .022″ thick.

Rubber band or gasket—$\frac{3}{4}''$ wide, $2\frac{3}{8}''$ double length, very soft and elastic.

Front electrode—carbon, hard and polished, $\frac{21}{32}''$ diameter, $\frac{1}{16}''$ thick.

Back electrode—carbon, hard and polished, $\frac{11}{16}''$ diameter, $\frac{1}{16}''$ thick.

Mica diaphragm—$\frac{27}{32}''$ diameter, very thin.

Back electrode chamber—inside diameter, $\frac{3}{4}''$, depth $\frac{5}{32}''$, clearance between sides of electrode and walls of chamber $\frac{1}{32}''$.

Distance between electrodes about .04″.

Damping spring—spring steel, $\frac{11}{32}''$ wide, .010″ thick, $1\frac{7}{16}''$ long; bent at right angles when not in place. The one which rests near center of diaphragm is tipped with soft rubber and also with felt; the outer spring, with rubber only.

Fig. 40 illustrates the Colvin transmitter. Although this is an efficient instrument and extremely unique in design, it is very little used. The shell is formed of two pieces, *A*, provided with the usual mouthpiece, and *B*, fitting into a recess in the piece, *A*. The space in which the diaphragm fits is made large enough to hold the diaphragm very loosely so that it and the cell it carries may vibrate with great freedom under the impact of sound waves. Upon the diaphragm is supported a hollow cylindrical cell, *D*, of insulating material (shown in the small cut at the

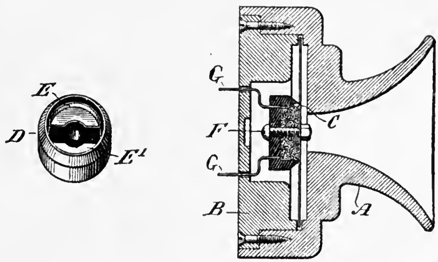


Fig. 40.—The Colvin Transmitter.

left), carrying two metallic electrodes, *E E′*, insulated from each other. To these electrodes are connected the circuit terminals, *G G*. The shell, *D*, is clamped firmly to the diaphragm, *C*, by a bolt, *F*, thus closing the chamber containing the granules. To prevent the access of moisture to the carbon granules the joint between the diaphragm and the edge of the shell is hermetically sealed. The diaphragm is of aluminum, and being loosely mounted is free to vibrate with great amplitude. One of the striking features of this instrument is that the two electrodes, *E E′*, are fixed with relation to each other, the variation in resistance being obtained by the variation in pressure between the electrodes and the carbon granules, due to the inertia of the latter, and also to the shaking up of the granules themselves, and the consequent variation of their intimacy of contact with each other.

Fig. 41 shows the Sutton transmitter now manufactured by

the Phœnix Interior Telephone Company. The variable resistance parts comprise a pair of carbon buttons, *F* and *G*, each surrounded by a sleeve of cloth, *H* and *I*, the abutting edges, *h* and *i*, of which are frayed out so as to form an intimate but yielding contact. These not only serve to damp the vibrations of the diaphragm, but form with the buttons, *F* and *G*, a closed chamber in which the granular carbon is placed. The button, *F*, is secured to the diaphragm, *K*, as shown, while the button, *G*, is

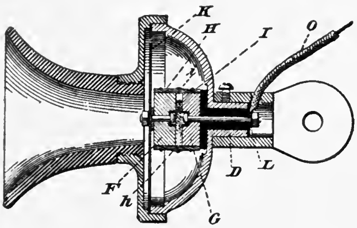


Fig. 41.—The Sutton Transmitter.

rigidly secured to the case of the instrument, and is insulated therefrom. The wire, *O*, leading from the bolt, *L*, which secures the button, *G*, in place, forms one terminal of the instrument, the casing itself the other.

The Ericsson transmitter, manufactured in Sweden, is being imported into this country to a considerable extent as a companion piece to the Ericsson receiver. This transmitter gives a very clear, soft tone, and requires little battery power. On the

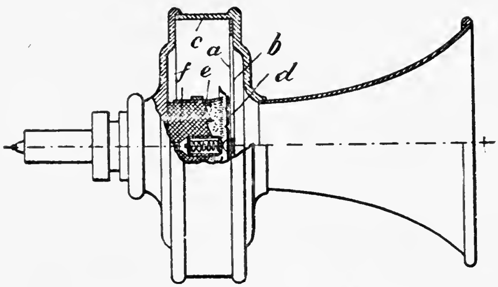


Fig. 42.—The Ericsson Transmitter.

whole it is a very efficient instrument. It is shown in section in Fig. 42, in which *a* is the sound-receiving diaphragm held against a shoulder in the brass casing, *c*, by two thin leaf-springs, not shown, each spring having two branches, so as to give in all four points bearing on the diaphragm.

For preventing moisture, especially the moisture contained in the breath, from entering beyond the diaphragm in the casing in which the diaphragm and other parts of the microphone are situated, a thin disk, *b*, of silk impregnated with lacquer is placed in front of the diaphragm, *a*, between it and the mouthpiece. The border of the disk *b*, as well as that of the diaphragm, *a*, is close to the wall of the casing, *c*.

The metal plate, *d*, mounted on the rear side of the diaphragm forms the front electrode, and for that purpose is gold-plated. The backwardly bent rim of the plate, *d*, surrounds the fore part of a soft ring, *e*, on the carbon block, *f*, and serves to prevent the carbon grains from falling out of the chamber. This soft ring is made of raveled felt, and does not impede the movements of the

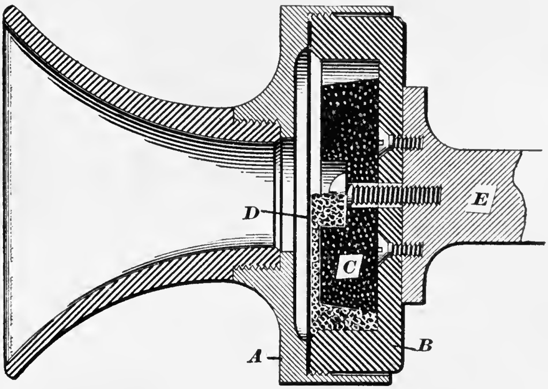


Fig. 43.—Western Telephone Construction Co.'s Transmitter.

diaphragm further than to prevent their amplitude from becoming too great for good transmission.

The diaphragm is further damped by the coiled spring resting in a chamber in the center of the carbon electrode. This spring rests on a tuft of cotton or felt, which in turn bears on the center of the front electrode.

The transmitter of the Western Telephone Construction Company (Fig. 43) is probably the simplest manufactured. The whole front case, *A*, of the transmitter is of a turned brass casting. It is shouldered inside to form a seat for the diaphragm, *D*, and threaded to engage an insulating cup, *B*, carrying the back electrode, *C*. This cup is screwed directly on a flange of the rocker arm, *E*, from the inside. The central screw which holds the back electrode in place also passes into the iron rocker arm, thereby making it one terminal of the transmitter. The back electrode, *C*,

is large, being $1\frac{1}{2}''$ in diameter and $\frac{3}{8}''$ thick. The chamber in which this block is mounted allows about $\frac{1}{8}''$ space all around the electrode, which space, as well as that between the diaphragm and the back electrode, contains granular carbon. The diaphragm, *D*, is of carbon, usually .016″ thick and $2\frac{3}{16}''$ in diameter, the free portion being $1\frac{13}{16}''$ in diameter. The distance between the back electrode and the diaphragm is $\frac{5}{64}''$. If the entire space in the chamber were filled with granules, the whole rear surface of the diaphragm would serve as a front electrode. The space, however, is only half filled, and only the lower half therefore is actively engaged as an electrode.

It would seem from theoretical considerations that better results would be obtained by using only the center of a carbon

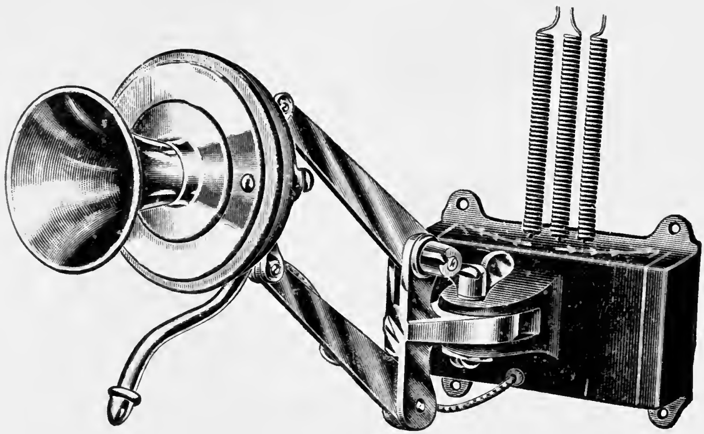


Fig. 44.—American Electric Transmitter.

diaphragm as the electrode and covering up all other portions. Many companies are following this idea; but a careful series of experiments have failed to show this to be true. The transmitter described above is powerful and articulates well.

Fig. 44 is chiefly interesting as illustrating a form of rocker arm made by the American Electric Telephone Co. This arm not only enables the transmitter to be adjusted as to height, but also laterally so that it may be pushed back out of the way.

The transmitter manufactured by this company and shown in this cut resembles the "solid back" in external appearance. It has a diaphragm of thin iron to which a thin carbon electrode is riveted. The back electrode is mounted in an insulating block and surrounded with a layer of cloth, which rests lightly against the diaphragm and holds the granules in place.

In granular-carbon transmitters much trouble has been experienced from what is commonly known as "packing." This is sometimes caused by the granules settling into a compact mass by the constant agitation due to the sound waves. As a natural result the granules arrange themselves in layers according to their size, the small ones working toward the bottom. In this state the entire mass becomes very compact, thus losing the advantages of loose contact and impairing the transmitting qualities of the instrument.

Sometimes packing is caused by a few granules becoming wedged between the diaphragm and the back electrode, thus preventing the free vibration of the diaphragm. Nearly all transmitters may be packed by pressing the lips firmly against the mouthpiece and sucking in the breath. The diaphragm is thus strained away from the back electrode and the granules settle into the space so formed. When the diaphragm is re-

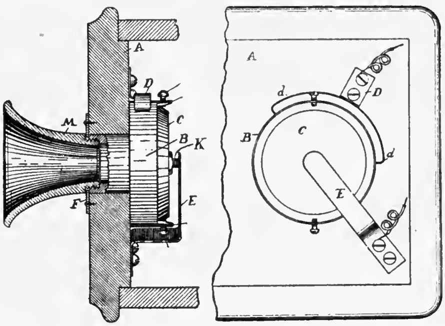


Fig. 45.—Transmitter with Mouthpiece Agitator.

leased it binds tightly against the granules, and the transmitter is thus rendered perfectly "dead." A sharp rap from beneath will often restore it to its former efficiency.

Another cause of packing is moisture from the breath of users of the telephone, which soaks through or around the diaphragm and destroys the "life" of the electrodes. For this reason hermetically sealed transmitters are desirable.

Fig. 45 shows a simple contrivance for preventing packing. *A* represents the front of the transmitter box and *B* the brass shell containing the working parts of the transmitter. A cylindrical portion of the shell extends through the front board, *A*, and carries the mouthpiece, *M*. *C* is the hard-rubber back plate of the transmitter. The spring, *E*, presses against the screw, *K*, projecting from the center of the back plate, *C*, and forms one

terminal; the spring, *D*, having two arms, *d d*, bearing against the casing, *B*, forming the other. By manually turning the mouthpiece the entire casing of the transmitter and the parts contained therein may be rotated, and the granular carbon, always falling to the bottom of its containing chamber, is effectively stirred up. The arms, *d d*, of the spring, *D*, make a sliding contact on the casing, *B*, while the screw, *K*, turns pivotally under the spring, *E*. This arrangement effectively remedies the packing difficulty, but much trouble is often caused by poor contacts between the springs and the parts of the transmitter on which they rest.

Means have also been devised for automatically turning the transmitter or otherwise agitating the carbon by the removal of the receiver from the hook. These, however, have not generally been found desirable.

In Fig. 46 is shown a transmitter recently designed by Mr. T. F. Ahearn, which is interesting as showing one of the many

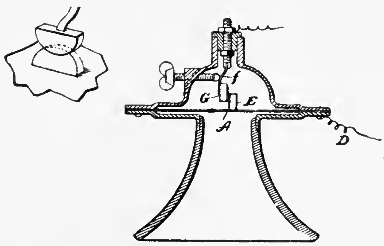


Fig. 46.—Ahearn Transmitter.

attempts to produce changes in *area of contact* without changes of pressure.

E is a carbon electrode attached to the center of the metal diaphragm, *A*, and forms the terminal electrode to which the wire, *D*, is attached. This electrode consists of a plate or plates, of either semicircular or triangular form, as shown.

The back electrode, *G*, is of similar form and is carried on the spring, *f*, in such manner as to overlap and rest on the front electrode, *E*. The pressure between the two may be regulated by the thumb-screw, as shown.

It is claimed that in this no variation in pressure can be caused by the vibration of the diaphragm, but that the electrodes simply slide over each other, the shape of the surfaces in contact amplifying the changes in contact area.

Fig. 47 shows one of the attempts to increase the efficiency of the microphone, but results so far obtained from this and similar

experiments have not proved of sufficient value to warrant the additional complexity of parts. This instrument consists of a double Blake transmitter, with a pair of electrodes on each side of the diaphragm. The action of the electrodes, *e* and *i*, is the same as that of the electrodes of the regular Blake instrument. The electrodes, *d* and *h*, however, being on the side of the diaphragm toward the speaker, serve also to vary the resistance of their point of contact, but an increase in resistance between *e* and *i* is accompanied by a decrease in resistance between *d* and *h*, and *vice versa*. The induction coil used with this instrument has two oppositely wound primary coils, *M* and *N*. The coil, *M*, is in circuit with the pair of contacts, *d* and *h*, while the coil, *N*, is in circuit with the contacts, *e* and *i*. As these coils are wound in opposite directions, and as an increase of current flowing from the battery, *B*, through one of them is always accompanied by a decrease of current through the other, it follows that their inductive effects on the secondary coil, *S*, will be added.

A transmitter constructed with the idea of producing actual

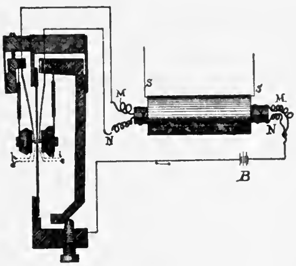


Fig. 47.—Double Transmitter.

alternations in the current flowing in the primary has recently been patented by Messrs. G. F. Payne and Wm. D. Gharky of Philadelphia. It is of unique design and produces very powerful results. It is designed to operate on the principle of a pole-changing switch, and in Fig. 48 its analogy to that familiar form of circuit-changing device is shown. The cuts in the upper portion of this figure show the two positions of a pole-changer, and it will be evident that the direction of current through the coil, *W*, will depend on the positions of the switches as shown by the arrows. In the lower portion of this figure the circuits and electrodes of the transmitter are diagrammatically shown. The electrodes, *K G* and *J*, are stationary, while electrodes, *M* and *N*, move in accordance with the vibrations of the diaphragm, being connected thereto by a piston-rod. As the movable electrodes are

by the action of the diaphragm impelled toward the left the resistance to the passage of a current between the electrodes, *N* and *G* and *M* and *K*, is diminished, while it is increased as between the electrodes, *N* and *J* and *M* and *G*. Consequently the greater part of the battery current will pass to and through the movable electrode, *N*, the stationary electrode, *G*, upward through the wire connection, *V*, thence through the wire connection, *U*, to the stationary electrode, *K*, and thence through the movable electrode, *M*, and to the battery. An impulse to the right brings the movable electrodes into the position shown at the right-hand lower cut, and reverses the conditions, producing, as there shown, a downward current through the wire, *V*, the changes from the one condition to the other being of course gradual and without sensible interruption, and the result being that the greater part of

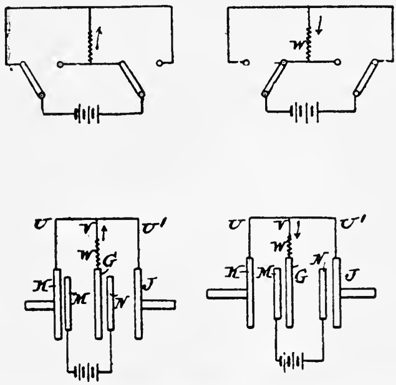


Fig. 48.—Diagram of Payne & Gharky Transmitter.

the battery current is sent through the coil, *W*, first in one direction and then in the other, following of course the movement of the diaphragm.

The construction of this transmitter is shown in Fig. 49, the lower portion of which shows an enlarged view of the electrodes. Parts *B* and *C* form the framework of the instrument, supporting the diaphragm and all working parts. *D* is a cylindrical box, in which the electrodes are situated, carried on the bracket, *C*. *G* is the central stationary electrode, constructed of brass with carbon faces and connected to one terminal of the primary coil, *W*. The outer stationary electrodes are each formed with stems, as indicated at *J* and *K*, which extend through the heads, *F F*, of the box, and are secured in proper position by the set-screws, *f f*. At the inner end of each rod is a brass disk (indi-

cated at J' and K'), J^2 and K^2, indicating brass disks screwing on the stems, J and K, and acting to clamp a light felt washer, L, between themselves and the disks, J', and K'. The disks, J' K', are each provided with a carbon facing, H. The movable electrodes, of which one is situated on each side of the central stationary electrode, are made up, as shown, of two brass disks, such as are indicated at M M and N N, a light felt washer, L, being clamped between the disks in each case. The electrode, N, is secured to the diaphragm by a light metal rod, O, one end, O^2, of which is shown threaded and screwing into the electrode end, while the other end, O', is threaded and screws into the nut, A'. This rod is

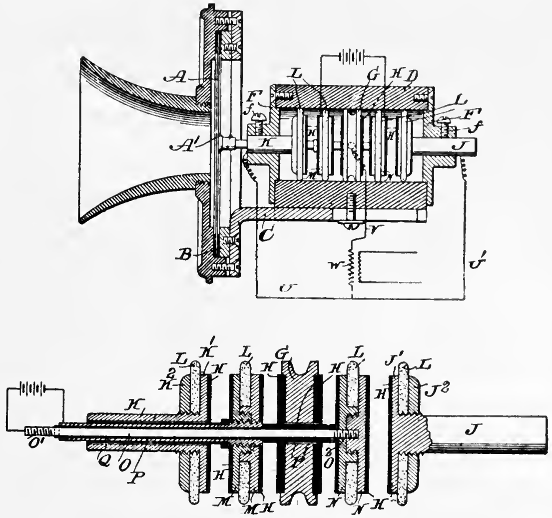


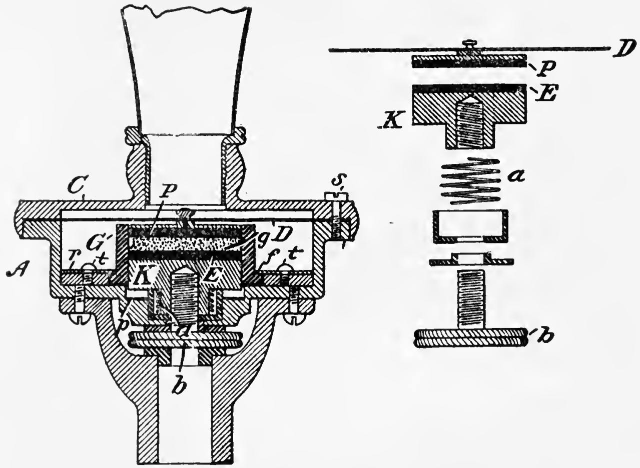
Fig. 49.—Details of Payne & Gharky Transmitter.

covered by a non-conducting jacket, P, which in turn is partly inclosed by a conducting-tube, Q, which connects with the electrode, M. The two electrodes, M and N, are thus rigidly bound to each other and to the diaphragm, but are insulated from each other. The battery is connected between them as shown.

Granular carbon is placed between each opposite pair of electrode-faces, there being thus four separate bodies of granular carbon, which are prevented from coming into contact with each other by the light felt washers, L.

Whether or not the effects produced by the action of these electrodes will be of great enough gain to overcome the objectionable complication, time must show; the results obtained, however, are remarkable.

Figs. 50 and 51 show an oddity in the form of a granular carbon transmitter devised by Mr. W. W. Jacques of the Bell Company. In the ordinary transmitter too much battery power is to be guarded against, as it throws the electrodes into vibration and causes the well-known squealing or sizzling sound. Mr. Jacques claims that when a multitude of electrodes in loose contact are normally kept in a state of rapid and continuous vibration by such a strong current, they are much more sensitive to sound waves falling upon them than they are when at rest. He gives as a probable explanation of this that the resultant normal pressure existing between the various pairs of electrodes is less when all of the electrodes are in vibration to and from each other than



Figs. 50. and 51.—Jacques Transmitter.

when they are at rest; and it is well known that, within certain limits, the sensitiveness of any microphone contact increases as the normal pressure is decreased.

He uses a current at a pressure of about 20 volts, which of course sets up a vibration of the granules, thereby maintaining them in the "desired condition of sensitiveness to sound waves." The use of such great battery power also allows the variation of a greater current than where the usual low voltage is used. He proposes to use this only on long lines and claims that "the undulations of current due to the vibrations of the electrodes of the transmitter produced by the normal action of the battery will fade out and disappear at a greater or less distance from the transmitter; while the undulations of current due to the action

of sound waves upon the normally vibrating electrodes will persist, and the sounds be heard in the telephone at the distant end of the line."

In order to stand such a heavy current the transmitter is made practically fireproof by the construction shown in Figs. 50 and 51, in which *A* is a cup-shaped metallic frame supporting the operative parts of the instrument. *C* is a metallic cover secured to the frame, *A*, by screws, *s*, clamping the diaphragm, *D*, in the ordinary manner.

G is a cylinder made of slate, having a flange, *f*, and secured to the interior of the cup-shaped frame, *A*, by a brass ring, *r*, which rests upon the flange and is there held by screws, *t*, screwing into the frame.

E is the back electrode, being a disk of hard carbon brazed to a brass disk, *K*, a projection from which lies, as shown, within a hollow projection, *p*, from frame, *A*, the two said projections being insulated from each other by a cup-shaped washer of vulcanized fiber. *P* is the front or working electrode, being a disk of hard carbon rigidly secured to the diaphragm, *D*, by a screw and nut. The two electrodes, *E* and *P*, fit the cylinder, *G*, closely. For a variable resistance material between them granulated carbon is employed, the grains being of such size that they will not pass between the peripheries of the electrodes, *E* and *P*, and the inner wall of the cylinder, *G*. These granules are kept in violent vibration by the strength of the battery current, while serving also as the variable resistance medium between the working electrode, *P*, and the back electrode, *E*, to take up the vibrations due to vocal waves in the ordinary manner.

The back electrode, *E*, is made adjustable by means of a spring, *a*, tending to push the brass disk, *K*, into the cylinder, *G*, and a brass thumb-screw, *b*. A flanged washer of vulcanized fiber insulates, frame, *A*, from the thumb-screw, *b*. The frame, *A*, is in metallic connection with the working electrode, *P*, while the thumb-screw, *b*, is in metallic connection with the back electrode, *E*. The noise in the receiving instrument, resulting from the two sets of vibrations in the transmitting instrument at the same end of the line, is not only painful to the ear, but interferes with the proper reception by the ear of sounds coming from the other end of the line. To obviate this difficulty, the receiving telephone is so constructed that the current coming from the transmitting telephone at the same end of the line is divided and passes around the core of the receiving instrument in two directions, while the current from the transmitting telephone at

the farther end of the line passes around the core always in one direction. The direction of the windings is such that in the former case the two windings neutralize each other and produce

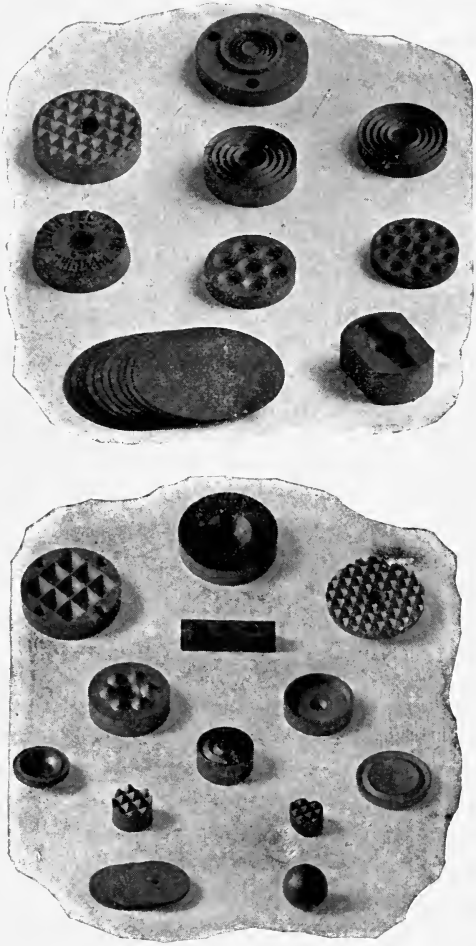


Fig. 52.—Carbon Electrodes for Transmitter.

no noise, while in the latter the effects of the two coils are added, thus giving the receiver its full power.

Fig. 52 is interesting as showing some of the standard transmitter electrodes and diaphragms used in this country. The cuts of these were loaned by Mr. M. M. Hayden of the Globe Carbon Co.

CHAPTER V.

INDUCTION COILS.

It has already been pointed out in the chapter on the History and Principles of the Battery Transmitter that the use of the induction coil is of decided advantage in that it allows the changes in the transmitter to bear a much larger ratio to the total resistance of the circuit in which these changes occur than would otherwise be the case; and further, that by virtue of the transformation from a comparatively low to a high voltage, the currents are much better adapted for traversing long lines and higher resistances. It may be further pointed out that with the same battery power the current in the primary circuit is much greater, owing to the lower resistance, than if the battery were placed in the line circuit, and therefore the transmitter is not only able to produce a greater relative change in the current flowing, but to cause these changes to act on a larger current.

It should be remembered that the current in the primary circuit is an undulating one and is always in the same direction. The current in the secondary, however, is alternating in character, changing its direction completely with every large fluctuation in the primary current. This latter feature is also productive of better results than would be the case were the current in the line wire of an undulatory character.

The size and quality of the iron core, the relation between the number of turns in the primary and secondary windings, and the mechanical construction of the induction coil are matters of the greatest importance, and have not in general received the attention which they merit. A number of attempts have been made to calculate mathematically the best dimensions and resistances of the telephone induction coil, but the matter is of such an extremely complex nature, and all of the quantities are subject to such complex and indeterminate variations, that the results so far produced have been in general unreliable.

Only a few series of experiments are on record from reliable sources giving the results of comparative tests between induction coils of various dimensions. It may be said that definite

results from any such series of tests are extremely hard to get, as the quality and loudness of transmission is subject to a very great personal error, even in the case of experienced experimenters. In making comparative tests of any telephone apparatus it is of the greatest importance that all possibility of prejudice on the part of the experimenter be removed, and in order to do this it is essential that he be in ignorance at all times of the particular instrument that he is testing. To illustrate this point, suppose that three transmitters are being compared with respect to determining the general talking qualities of each. If the party at the receiving telephone, who is to judge of the hearing, desires that one of these instruments produces better results than the others, he is very sure, even though he be strictly honest with himself, to conclude at the end that that transmitter is by far the best; unless, of course, there is a very marked difference between them. For this reason he should be kept in ignorance of the particular transmitter in circuit with the line at any time, and should only be told when changes are made. It is well to have the instruments numbered, the party judging of the merits to be in ignorance of the transmitters to which those numbers refer.

It is also a somewhat difficult matter in comparing the clearness with which instruments transmit or reproduce speech to select proper subject matter to be transmitted. It is unfair to the first instrument tested to repeat the same sentence or read the same matter in each case, for the reason that the listening party becomes more or less familiar with the matter to which he is listening, and therefore often catches words at the second or third reading which he fails to grasp at the first. It is therefore better to read a selection from a certain article in the first test, and a continuation of the same matter in each successive test, so that the character of the matter read will be approximately the same in each case. However, where several instruments are apparently of almost the same merit, and where the transmission is so good that all of the matter may be generally understood, it has been found that a better way is to prearrange a number of series of words, a different series to be read into each instrument under test. Care must be taken, in the selection of these words, that each series contains words of the same character.

To illustrate: suppose five instruments are to be tested. Five different series of words may be prepared, containing such words as the following:

1st	2d	3d	4th	5th
sign	rhyme	dine	fine	mine
going	rowing	sewing	mowing	throwing
missile	thistle	whistle	bristle	gristle
D	E	G	P	B
etc.	etc.	etc.	etc.	etc.

Each list should contain about forty words; and as the words in each series will be seen to differ from the corresponding words in the others to only a slight extent, no instrument can be said to have an easier list than the others. The first list should be read into the first instrument slowly enough for the receiving party to write them down. Then the second list is read to the second instrument, and so on.

Such words are difficult to distinguish, especially when there is no context, as is the case in reading an arbitrary list of words. The receiving party should be required to write down the words as he hears them, and the list which is most correct according to his notes will probably represent the work of the best instrument so far as clearness is concerned. It is only by a consideration of such details as these, simple though they be, that an unbiased opinion can be formed as to the relative merits of telephonic apparatus.

Many elaborate experiments have been performed for arriving at the comparative merits of similar instruments depending on the quantitative measurements of the amplitude of vibrations, the amount of current, and similar quantities, but in the first place the apparatus and time for such measurements are available to but few, and in the second place it is doubtful if the results obtained are as reliable as those obtained by carefully following the above suggestions in a conscientious manner.

Such quantitative experiments are, however, of great importance in adding to our knowledge of the true workings of the telephone, thus greatly aiding in the development of the art in general.

A series of experiments, cited by Preece and Stubbs and performed by the administration of the Swiss telephone department, is of great interest. In this test a good Blake transmitter was used throughout, the object being to determine the best of a set of ten induction coils. Table I gives complete data concerning the primary and secondary windings of each coil.

The results obtained over five different lengths of line are shown in the right-hand portion of the table. In each case the inten-

TABLE I.

Number of Coil.	Primary Winding.			Secondary Winding.			Results for Various Lengths of Line.									
							.31 mile		38 miles		49 miles		53 miles		67 miles	
	Number of Convolutions.	Number of Wire, B. & S.	Resistance Ohms.	Number of Convolutions.	Number of Wire, B. & S.	Resistance Ohms.	Intensity.	Clearness.	Intensity.	Clearness.	Intensity.	Clearness.	Intensity.	Clearness.	Intensity.	Clearness.
1	61	24	.25	1956	35	100	.3	.9	.9	1.0	.3	.7	.7	.8	.2	.9
2	62	24	.25	3191	35	180	.7	.9	1.0	1.1	.9	1.0	1.[illegible]	1.3	.7	1.0
3	62	24	.25	4080	35	250	.9	.9	1.0	1.3	.9	1.0	.[illegible]	1.3	.6	1.0
4	116	24	.50	3952	35	250	1.5	1.3	1.7	1.5	1.3	1.5	1.[illegible]	1.5	1.2	1.5
5	230	24	1.00	3865	35	250	1.3	1.0	1.3	1.2	1.1	1.3	1.[illegible]	1.5	1.0	1.3
6	232	24	1.20	4420	35	300	1.5	.9	1.6	.9	1.7	1.3	1.[illegible]	1.6	1.5	1.5
7	295	24	1.50	4278	35	300	1.3	.9	1.5	.9	1.1	1.1	1.[illegible]	1.4	1.6	1.3
8	368	24	2.00	4735	35	350	1.3	1.0	1.5	.9	1.1	1.0	1.[illegible]	1.4	1.6	1.2
9	368	21	1.17	4735	29	130.2	1.7	1.0	1.6	.9	1.7	1.4	1.[illegible]	1.6	1.7	1.3
10	1350	24	10.00	3950	35	400	.3	.3	.3	.5	.3	.3	[illegible]	.4	.3	.1

sity and clearness of the Blake transmitter with a standard coil was taken as unity, and the results are expressed in terms of this standard. The resistance of the primary wire of this coil was 1.05 ohm and that of the secondary 180 ohms. It will be noticed from the results that coils Nos. 4, 6, and 9 were, all things considered, the best, while coils Nos. 1 and 10 were very inferior. The table also shows in general that a coil that was good for a short distance was also good for a long distance, and this is perhaps the most instructive lesson to be gained from these tests. It is hard to draw any definite conclusions from the performances of the various coils as to their relative merits and to point out why coils Nos. 4, 6, and 9 should give better results than the others or why coils Nos. 1 and 10 should be so much inferior. It shows, moreover, that good results may be obtained with the same transmitter and with coils differing widely as to their characteristics; this being shown particularly in the case of coils Nos. 4 and 9, the former having a secondary of 250 ohms and a primary of $\frac{1}{2}$ ohm, while the latter had a secondary of 130 and a primary of 1.17 ohm. The coil adopted for the Blake transmitter in this country has a primary winding of $\frac{1}{2}$ ohm and a secondary of 250 ohms, which, it will be seen, corresponds exactly to coil No. 4 in this table, which gave the best results. The tendency, however, among the manufacturing concerns whose practice may be considered the best, is to reduce the ratio of transformation by making the secondary windings very much lower than was form-

erly the case. As an extreme example of this, it may be cited that the coil used to a large extent with the solid-back transmitter on the long-distance lines of the American Telephone and Telegraph Co. has a primary of .3 ohm and a secondary of but 14 ohms resistance. This coil is provided with a very large core composed of a bundle of soft-iron wires, and its total length between the cheeks is six inches. The results obtained leave no doubt as to the efficacy of this construction.

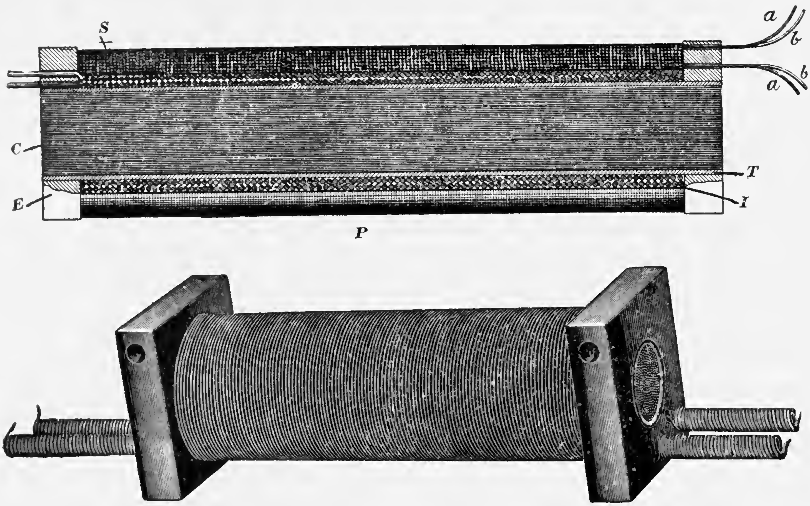
The particular coil to be used with any style of transmitter and battery should be carefully determined experimentally at the start, and having once been decided upon, should not be changed except for very positive evidence that the change is for the better.

The determination of the proper size and dimensions of a standard coil is no easy matter, and probably the best way is by a process of elimination. When carried out properly, however, even this is a somewhat expensive and tedious operation. Having decided on the general dimensions of the core, about a dozen of them should be made up and wound with primary coils, using conductors ranging from, say, No. 18 to No. 30 B. & S. gauge, using in each case two or three layers of these wires only. This will give a set of cores all alike, having primary coils ranging from perhaps $\frac{1}{8}$ of an ohm to 8 ohms. After this a number of secondaries should be wound on spools, adapted to slip over the primaries. These may be wound to resistances ranging from 10 to 500 ohms, always using a large enough wire to approximately fill the available wire space. This will make available a larger variety of induction coils than would probably be obtained in any other way, for it is evident that each primary may be used with each one of the secondaries.

In conducting the experiments, one of the primary coils should be chosen, and the results tested by using each one of the secondaries successively in connection with that primary. The best of these combinations should be noted, and then another primary should be tried in a similar manner with all of the secondaries. In like manner all of the primaries should be tried with all of the secondaries, note being made of the best combination in each case. In this the best secondary for each of the primary coils chosen will be known, and, in order to arrive at the final result, a comparative test should then be made in a similar manner with each of these combinations. This process may be carried out with as great a degree of refinement as time and patience will permit; and after the best combination has

been found for any particular size of core, the entire operation may be repeated as many times as is desired, using different sizes of core.

Fig. 53 shows a sectional view, and Fig. 54 a perspective view, of a coil the dimensions of which were determined by a method not unlike that just described. This is the coil used with the transmitter of the Western Telephone Construction Co., shown in Fig. 43, and has proven itself to be adapted for almost any variety of work. The core, *C*, is formed of a bundle of about 500 strands of No. 24 B. & S. gauge Swedish iron wire, and is 4 inches in length and $\frac{9}{16}$ of an inch in diameter. The spool is formed of a thin fiber tube, *T*, over the ends of



Figs. 53 and 54.—Section and Perspective View of Induction Coil.

which are slipped the heads, *E*, of similar material, the parts being glued together. On this core are wound about 200 turns of No. 20 single silk-covered wire. This is two layers deep, so that the ends of the primary both emerge from the same end of the coil. Over the primary winding are wrapped several layers of oiled paper, after which the secondary is wound, this consisting of about 1400 double turns of No. 34 wire, two in parallel. These two wires are wound side by side throughout their length, and give the equivalent area of one No. 31 wire. The resistance of the primary coil is .38 ohm and that of the secondary 75 ohms. The terminals of the secondary coil are shown at *a b* and *a b*. in Fig. 53. After the coil is wound, the small wires

of the secondary are attached to larger wires inside of the spool-head, so that the danger of breakage will be diminished. These leading-out wires should be coiled in a tight spiral, in order to avoid breakage and also to give a considerable length of wire in making connections where it is needed.

A coil constructed on somewhat radical principles is shown in Fig. 55, this being manufactured by the Varley Duplex Mag-

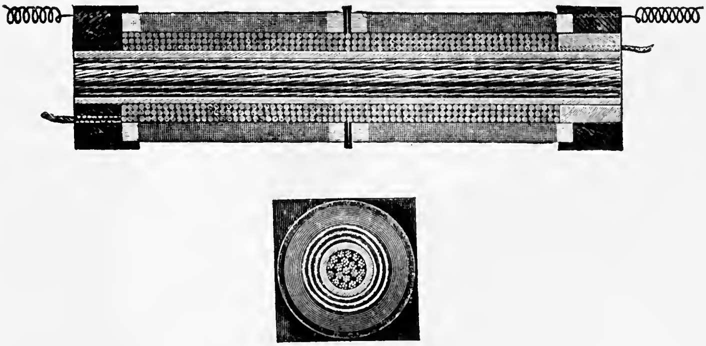


Fig. 55.—Varley Induction Coil.

net Co. The core consists of a bundle of small soft-iron cables, each cable being composed of seven strands of rather fine Swedish iron wire. On this the primary, consisting of three layers of cotton-covered magnet wire, is wound. The secondary is wound in two sections, as shown, and the right-hand head of the spool is made removable, so that each section may be slid on or off, as needed, in making repairs. The most unique feature in this coil is the fact that bare wire is used in winding the secondary. These coils are wound by special machinery, and the

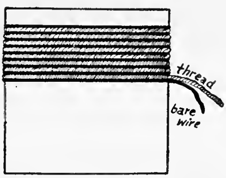


Fig. 56.—Manner of Winding Varley Coil.

adjacent convolutions of the wire are held apart by a fine thread of silk wound alongside and parallel with the wire, as shown in Fig. 56. A layer of paper is introduced between each layer of wire, and in this way the insulation is made complete. The machines for winding in this manner have been perfected with such nicety that the layer of paper is automatically introduced

between each winding without stopping the machinery, which is run at a very high speed. Considerably more wire can be placed on a coil in a given space than with the ordinary method of winding; and, of course, the fact that bare wire is used, renders the coil cheaper.

This same company has recently carried the idea of sectional

Fig. 57.—Transmitter Mounted on Arm.

windings throughout the entire field of telephone work. They construct their spools in such manner that the heads may be readily removed and a coil replaced without the necessity of re-winding. A comparative test made by the writer, using an induction coil wound in the ordinary manner with silk-covered wire and another coil wound with bare wire on the same size of core and with the same resistance of primary and secondary,

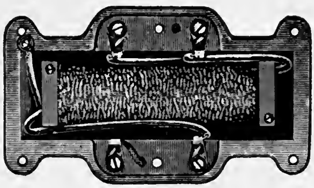


Fig. 58.—Induction Coil in Base of Arm.

showed a very slight advantage in favor of the latter, although the experiment was not carried far enough to warrant the conclusion that this would be true in every case.

It is now quite common to mount the induction coil in the base of the arm on which the transmitter itself is mounted, such

construction being shown in Figs. 57 and 58. This base and arm are made of cast iron joined as shown in such manner as to allow a considerable vertical movement of the transmitter, in order to accommodate it to the heights of different users. The coil is sometimes mounted upon the back-board of the telephone, but a more desirable method is to mount it in the arm-base, as shown, the various terminals being brought out to binding posts on the front of the base. This construction, however, is bad, unless well carried out, and great pains should be taken in insulating the various posts and wires from the conducting base. A considerable advantage has been claimed, due to the presence of the iron case about the coil, thus rendering the magnetic circuit more complete. This, however, is a point of doubtful validity, as it may be claimed with equal force that the presence of the case gives rise to eddy currents which would have a detrimental effect. As a matter of fact, the presence of the case has little appreciable effect one way or another on the quality of the transmission.

CHAPTER VI.

BATTERIES.

If a sheet of zinc and one of carbon be separated from each other and immersed in a liquid capable of chemically attacking the zinc, a difference of potential will at once be formed between the two plates. If the two plates are then connected together by a wire, a current of electricity will flow from one to the other through the wire, and while the current is so flowing the zinc will be eaten away by the solution with more or less rapidity. Such a combination is called a voltaic cell, and two or more of such cells may form an electric battery. Of course other substances than zinc and carbon may be used, it only being necessary that both plates be of conducting material and that one of them shall be of such a nature as to be chemically attacked by the fluid. The two plates of the cell are called electrodes, and the solution in which they are immersed the electrolyte.

The current is assumed to flow from the plate which is attacked through the electrolyte to the one which is not, and therefore in the cell under consideration from the zinc to the carbon plate. The plate which is attacked is therefore always called the positive plate or electrode, and the one which is not attacked the negative.

Starting from the surface of the zinc, where the chemical action is taking place, the current flows through the electrolyte to the surface of the carbon electrode, thence by means of the wire back to the zinc electrode.

It will be noticed that the current flows from the carbon to the zinc in the wire, outside the electrolyte; and therefore in order to make the terms positive and negative correspond to ordinary usage, the carbon terminal is called the positive pole and the zinc terminal the negative pole. It seems at first a little confusing to have a positive pole on a negative plate, and a negative pole on a positive plate; but if the direction of the current be kept in mind as being always from positive to negative, no confusion will arise.

The part of the circuit outside of the battery connecting the two poles is called the external circuit. The internal circuit is

of course through the two electrodes and the electrolyte, and the resistance of this latter path is called the internal resistance of the battery.

Zinc forms the active or positive element of the great majority of primary batteries, while the negative electrode is usually of carbon or of copper. No matter, however, of what materials the electrodes are formed, that which is attacked by the electrolyte while the battery is in action forms the positive plate of the cell, the current flowing always from it in the electrolyte.

In nearly all cases hydrogen is liberated from the electrolyte at the negative plate—that is, at the plate which is not attacked. This forms a film over the surfaces of the negative electrode which, unless removed or destroyed, tends to greatly weaken the strength of the battery, for two reasons: First, the film of gas is of very high resistance and therefore raises the internal resistance of the battery enormously, thus causing a correspondingly small flow of current; and second, the gas is itself attacked by the electrolyte, hydrogen having almost as great an affinity for the oxygen in the latter as has the electrolyte itself for the zinc. This causes a counter-electromotive force to be set up which to a large extent neutralizes that set up by the action of the electrolyte with the zinc. The phenomenon of the collection of hydrogen on the negative electrode in a cell is called polarization; and it is necessary to adopt some means to prevent it to as great an extent as possible, as otherwise a cell would become useless after a very short period of use.

The LeClanche type of battery, which has been and still is used to the greatest extent for telephone work, consists of a carbon negative electrode, a zinc positive electrode, and an electrolyte of a solution of sal ammoniac. The sal ammoniac attacks the zinc, forming zinc chloride and liberating hydrogen and also ammonia gas on the surface of the carbon. In order to get rid of the polarizing effects due to the hydrogen, black oxide of manganese, usually in small lumps, is in some way closely associated with the carbon. This oxide of manganese is exceedingly rich in oxygen, which slowly unites with the free hydrogen to form water. In use, cells of this type polarize rather quickly, but as soon as the external circuit is opened the cell slowly recovers, owing to a combination of the hydrogen with the oxygen as described above. This cell is therefore suitable only for cases where the circuit will be closed for a few minutes at a time; and as this is exactly the condition which is met in telephony, it has been found particularly suitable in this line of work.

The cell used almost exclusively by the Bell companies is shown in Fig. 59.

The zinc electrode is in the form of a rod, while the carbon electrode is imbedded in a porous pot which is immersed with the zinc in the electrolyte. Around the carbon within the porous pot is packed a mixture of black oxide of manganese and broken carbon, the former to act as the depolarizer and the latter to give greater conductivity to the mixture and to give a greater surface to the carbon electrode. One of these cells is almost invariably found in connection with the Blake transmitter.

A better form of cell than this is one using practically the same materials for its various parts, designed by Mr. M. M. Hayden of the Globe Carbon Works, Ravenna, O. This cell is shown in Figs. 60 and 61, the latter being a sectional view. The carbon electrode is in the form of a corrugated hollow cylinder, 1 (Fig. 61), which engages by means of an internal screw-thread a corresponding thread on the under side of a carbon cover, 2. Within this cylinder is a mixture, 10, of broken carbon and black oxide of manganese, the latter serving as a depolarizer.

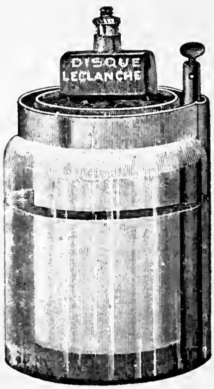


Fig. 59.—LeClanche Cell.

The zinc electrode, 6, is in the form of a hollow cylinder almost surrounding the carbon electrode, and separated therefrom by means of heavy rubber bands stretched around the carbon. The rod forming the terminal of the zinc passes through a porcelain bushing on the cover plate, so that a short-circuit cannot take place. The terminal pin, 8, is imbedded in a hole, 4, in the carbon cover, by first heating the cover to a high degree and then pouring in melted lead, as shown. This forms, with the nut, 7, and the washer, 6, a very secure form of connector for the positive pole. Unless some such precaution as this is taken, corrosion soon sets in around the metallic connection to the carbon, thus causing a poor connection. The Hayden cells are used to a very large and increasing extent by the independent telephone companies. They have an electromotive force of about 1.55 volts, and recuperate very quickly after severe use.

Many other forms of sal-ammoniac cells are in common use. Some of these consist merely of a zinc rod hanging in the center of a carbon cylinder, no depolarizer being furnished. In other

forms the carbons have molded with them the manganese depolarizer and are in various forms, but all act in the same general way.

The advantages of the LeClanche type of cell for telephone work are many. They are inexpensive in first cost and in renewals. They are very cleanly, giving out no noxious fumes and containing no highly corrosive chemicals. They require almost no attention, the addition of a little water now and then to replace the loss due to evaporation being about all that is generally required. They give a rather high electromotive force and have a moderately low internal resistance, so that they are capable of giving a considerable amount of current for

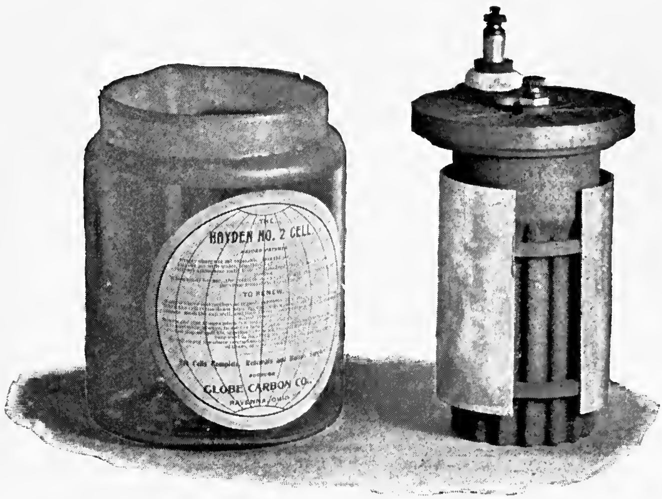


Fig. 60.—Hayden Cell.

a short time, and lastly, if properly made they recuperate quickly after polarization due to heavy use.

To set up and maintain cells of the LeClanche type place not more than four ounces of prime white sal ammoniac in the jar. Fill the jar one-third full of water and stir until the sal ammoniac is all dissolved. Then place the carbon and zinc elements in place. A little water poured in the vent-hole of the porous-pot forms will tend to hasten the action. Unless a cell is subject to very severe use, it will require but little attention if it is a good one. Water should be added to supply loss by evaporation. If the cell fails to work, examine its terminals for poor connections. If the zinc is badly eaten, replace it with a new one. If this fails to improve it, throw out the solution and refill as at first. If

now the cell does not work properly, the porous pot or carbon element may be soaked in warm water, and if this gives no better results they should be replaced. In the Hayden cell, the depolarizer may be removed by unscrewing the carbon from the cover.

The Bell Company is now using in its long-distance work, in connection with the solid-back transmitter, another form of cell known as the "Standard" Fuller. In this the positive electrode

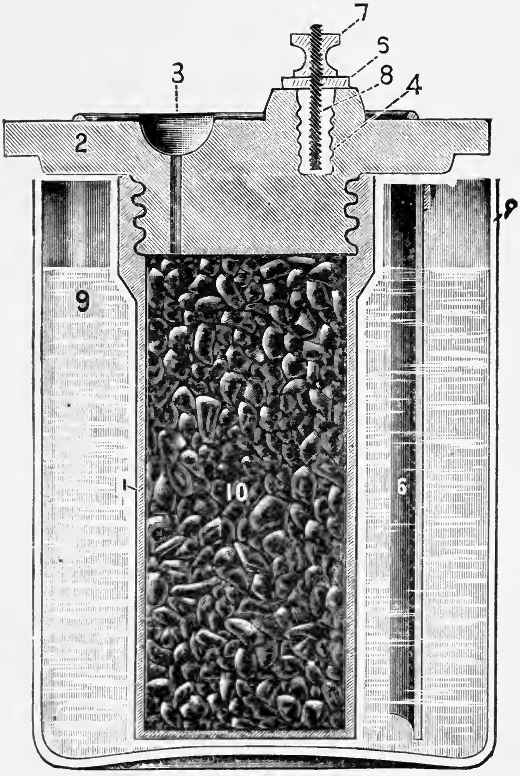


Fig. 61.—Sectional View Hayden Cell.

is a heavy block of zinc molded into conical form around a heavy copper wire, which forms the negative pole. The negative electrode is a block of carbon hanging through a slot in a wooden cover. The separate parts are shown in Fig. 62. The zinc rests in the bottom of a porous cup when in place. The electrolyte for this cell is made as follows:

Sodium bichromate,	6 ounces
Sulphuric acid,	17 ounces
Soft water,	56 ounces

Dissolve first the sodium bichromate in the water and then add slowly the sulphuric acid. (Never pour the water into the acid.) The mixture should be made in an earthen vessel, or if in a glass jar the jar should be placed in cold water in order to prevent overheating.

Another solution called electropoin fluid may be used as the electrolyte in this cell. It is made with bichromate of potash instead of bichromate of sodium.

The cell is set up according to the following directions:

Place the quantity of solution made by the above formula in the glass jar.

Put one teaspoonful of mercury in the bottom of the porous

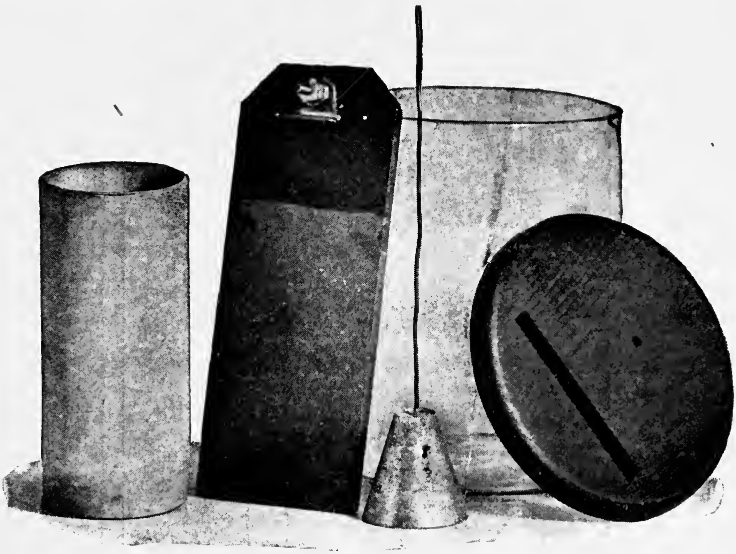


Fig. 62.—Parts of "Standard" Fuller Cell.

cup, add two teaspoonfuls of common salt, place the zinc in the bottom of the cup, and fill to within two inches of the top with soft water.

Place the porous cup in the jar and put on the cover, passing the wire from the zinc through the hole provided for it. The cell is then ready for use.

The active element in the electrolyte in this cell is the sulphuric acid, which of course attacks the zinc. The bichromate of sodium or of potash serves as a depolarizer, the oxygen in it combining with the hydrogen, liberated at the positive pole, to form water.

The specifications for this cell, as used by the New York Telephone Company and some other large Bell concerns, are in substance as follows:

One cell of Standard Battery shall consist of the following parts: 1 glass jar; 1 wooden cover; 1 carbon plate with binding post

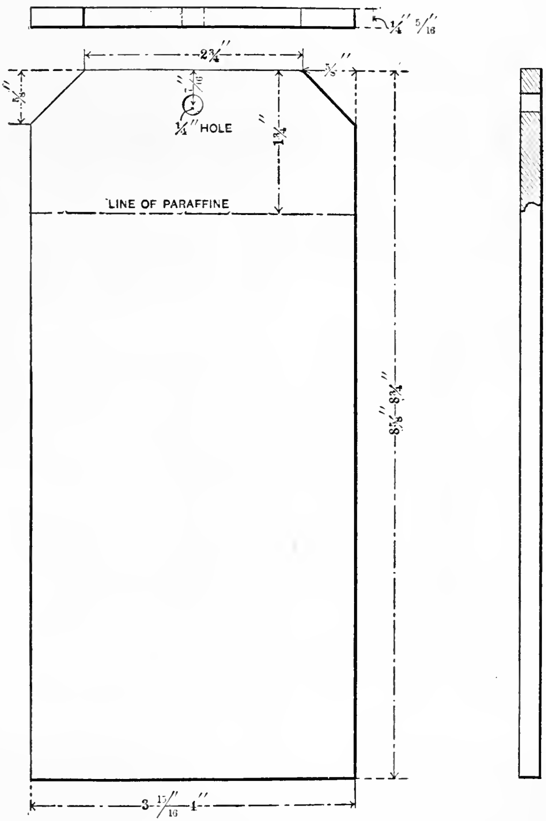


Fig. 63.—Carbon Plate for "Standard" Fuller Cell.

and locknuts; 1 cast zinc; 1 porous pot—all as hereinafter specified.

Glass Jar: The glass jar shall be of first quality flint glass, cylindrical in form, 6 inches in diameter and 8 inches in depth.

Wooden Cover: The cover shall be of clear kiln-dried whitewood. It shall be thoroughly coated with two coats of asphalt paint, and be of such dimensions as to form a proper cover for the jar.

Carbon Plate: The carbon plate shall be of the form and

dimensions shown in the drawing (Fig. 63). It shall be of good quality, homogeneous and free from flaws, cracks, and other defects, and completely carbonized. Each carbon shall be provided with a clamp of the form and dimensions shown in the drawing (Fig. 64). The parts of the clamp shall be of bronze, and shall be nickel-plated. Before attaching the clamp to the carbon, the carbon shall be heated to a temperature of at least 250 degrees Fahrenheit, and the top portion of it, to the extent indicated in the drawing, shall be immersed in paraffin at a temperature of about 250 degrees Fahrenheit, the immersion to continue until the immersed portion of the carbon is saturated. After the clamp is attached to the carbon, but before the locknuts are in place,

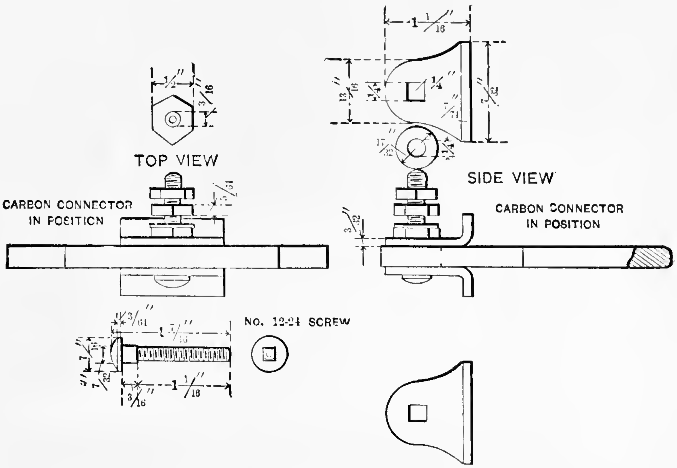


Fig. 64.—Details of Clamp for "Standard" Fuller Cell.

the carbon shall be immersed in melted paraffin at a temperature less than 170 degrees Fahrenheit. The carbon plate is then to be completed by attaching the locknuts.

Cast Zinc: The zinc shall be of the form and dimensions shown in the drawing (Fig. 65). It is to be made of Rich Hill spelter. Cast into the zinc shall be a soft copper wire .1018 of an inch in diameter (No. 10 B. & S. gauge). The zinc and the copper wire shall be amalgamated to a height of 4 inches.

Porous Pot: The porous pot shall be cylindrical in form, 3 inches in diameter and 7 inches deep.

The "Standard" Fuller cell made according to the above specifications gives an E. M. F. of 2.1 volts, and is exceedingly well adapted for heavy telephone service. A still more powerful

cell, and one somewhat more convenient to handle, is shown in (Fig. 66).

In this the zinc is very heavy, and in order to present a greater surface to the electrolyte has a horizontal cross-section in the form of a cross. The carbon electrode is in the form of a hollow cylinder completely inclosing the porous pot. The carbon cylin-

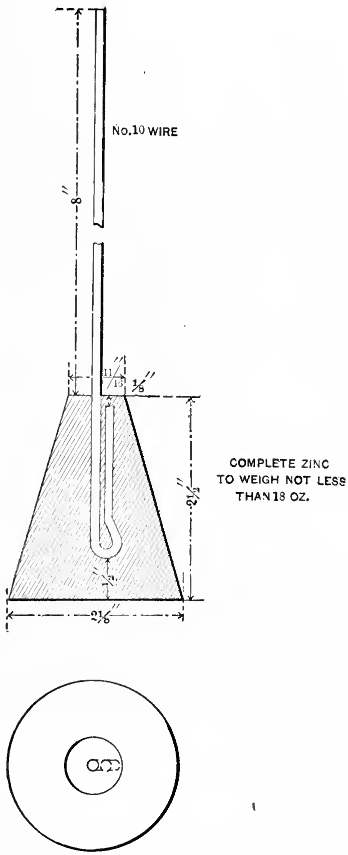


Fig. 65.—Zinc for "Standard" Fuller Cell.

der has a flaring top provided with a flange which fits over the upper edge of the glass jar, thus forming a very complete cover for the entire cell.

The following are the data given by the Globe Carbon Co. concerning the main points of this form of Fuller cell:

E. M. F., 2.1 volts.

Current, about 8 amperes.

Carbon, $4\frac{1}{2}$ inches diameter by $8\frac{1}{2}$ inches over all.

Carbon surface exposed to solution, 156 square inches.

Zinc weighs 2 pounds; $2\frac{1}{4}$ inches across; total length, 8 inches.

Zinc surface exposed, 54 square inches.

Porous cup, 3 inches diameter, 7 inches long.

Jar, 6 inches diameter, 8 inches deep.

Solutions same as "Standard" Fuller cell.

Cell, complete, weighs 8 pounds 12 ounces.

The internal resistance of Fuller cells is very low, especially in the cylindrical carbon type. They will stand for several months on open circuit with but little local action.

Formerly three cells in series, giving six volts, were used with the solid-back transmitter, but it has been found that two cells give, all things considered, as good or better results.

Still another form of battery, of entirely different type, is shown in Fig. 67. This is known as the gravity battery, and is used to a

Fig. 66.—Parts of Globe Fuller Cell.

very large extent in telegraph service, and also in telephone work where it is necessary to have a small but constant current always flowing. In this cell the negative electrode is of sheet copper, 3 strips of which are riveted together at their centers, after which the ends are bent outwardly, so as to present a large surface to the electrolyte. The zinc is in the form of a "crow foot," cast with a lug adapted to hook over the edge of a glass jar. In setting up this battery the copper is first put in place in the bottom of the jar. Sulphate of copper, or blue vitriol, as it is called, is then filled in around the copper to a height almost sufficient to cover it. The jar is then filled with water and the zinc put in place.

In this battery sulphuric acid is formed, which attacks the zinc

to produce zinc sulphate. This fluid is lighter in weight than the solution of copper sulphate and therefore occupies the upper portion of the cell. The fact that the two solutions in this battery are kept apart by gravity instead of by the use of a porous pot, as in the Fuller cell, is accountable for the name, "gravity cell." As the zinc sulphate is colorless, while the copper sulphate is of a dark-blue color, the separating line between the two liquids is easily distinguished. This line is termed the "blue line," and should be kept about midway between the copper and the zinc. If the blue line rises too high, so as to come in contact with the zinc, it should be lowered. This can be done by short-circuiting the battery for a short time, or by drawing off some of the blue fluid with a siphon and filling in with water or with zinc sulphate from another battery. In cases, however, where the battery is in constant use, it very rarely happens that the blue

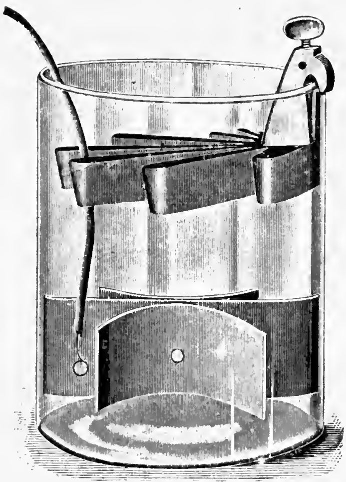


Fig. 67.—Gravity Daniell Cell.

line reaches too high a level, and the reverse is more likely to take place. If the blue line reaches the upper portion of the copper, more crystals of bluestone should be dropped in, and if this does not remedy the difficulty some of the zinc sulphate from the top of the cell should be siphoned out and replaced by clear water. These batteries are very satisfactory for closed-circuit work, but are not well adapted for telephone work in general on account of their high internal resistance.

When a battery is on open circuit there should be no action between the electrolyte and the zinc. This would be the case

were it economical to use perfectly pure zinc, but inasmuch as commercial zinc always contains impurities, frequently consisting of other metals, a local galvanic action is set up, the impurities forming with the zinc minute galvanic couples. In order to reduce this action to a minimum, it is advisable, especially in such cells as the Fuller, to amalgamate the zinc—that is, to coat it with mercury. This seems to form a perfectly homogeneous surface to the zinc, which prevents local action. The fact that this local action takes place on account of impurities in the zinc makes it very clear that the quality of metal used is a matter of very considerable importance.

STORAGE BATTERIES.

If two plates of lead are immersed in a weak solution of sulphuric acid, no difference of potential will be established between them, because the acid, if it acts on them at all, does so to an equal extent on each plate. If now an electric current, as from a battery or a direct-current dynamo, is sent through the two plates and the solution between them, a redistribution of materials will take place in the cell. The electrolyte will be decomposed, the oxygen in it forming, with the plate to which the positive terminal of the charging source is connected, lead peroxide; while hydrogen is liberated at the plate to which the negative terminal is connected. On disconnecting the source of current, the cell, which was before incapable of producing a difference of potential, is found able to drive a current through a circuit formed by connecting its poles together by a wire or any other conductor. The combination has become a voltaic couple. The current from this couple always flows in a direction opposite to that of the charging current.

The cell, consisting of two lead plates in a solution of sulphuric acid, was devised by Gaston Planté, and is the prototype of all modern storage batteries or accumulators. Nearly all commercial cells, of which there are many good ones, have the plates coated with some compound of lead, rich in oxygen. This is changed by the charging current into lead peroxide on the positive plate, and to spongy lead on the negative.

In storage cells of considerable size it is customary to use more than two plates, all the positive plates being connected together by a heavy strip of lead, and likewise all the negative plates by another similar strip. There is usually one more of the negative than of the positive plates, the arrangement being such that the plates are alternately positive and negative.

The setting-up and operating of storage batteries is a very simple matter, yet there are a few mistakes to be guarded against, which if made are liable to injure or ruin the battery. The electrolyte is usually formed of four or five parts of water to one of acid. These should be mixed in an earthenware vessel by slowly pouring the acid into the water, and not the water into the acid.

In charging storage batteries the positive terminal of the dynamo or other source of current is connected to the positive pole of the battery, and the negative terminal of the dynamo to the negative pole of the battery. A simple test, and the most reliable one, for determining which is the positive pole of any source of current is to dip wires leading from both terminals into a small vessel containing slightly acidulated water. Bubbles of gas will be given off from each wire, but at a very much higher rate from the wire leading to the negative pole than from that leading to the positive. The poles of the charging dynamo should always be determined with absolute certainty before connection is made to the terminals of the storage battery, for a reversal in the connections is very likely to ruin the battery.

The manufacturers of storage batteries usually furnish directions concerning the proper rate of charge and discharge for a battery of a given size. These should be followed as closely as conditions will allow.

The most accurate method of determining the condition of a cell is by the use of a hydrometer for measuring the density of the electrolyte. It is usual to have the normal density of the solution about 1.180; when it becomes as low as 1.170 the cell may be considered fully discharged, and when as high as 1.250 fully charged. These figures will vary somewhat with different forms of battery.

Water only should be added to replace loss by evaporation, while spilled solution must be replaced by the regular acid solution according to formula.

The extremely low internal resistance of storage batteries, and the fact that their voltage is high (2 volts) and constant and that they are not subject to polarization, make them, all things considered, the ideal source of current for telephone work. They are being largely used for supplying the operators' transmitters in large central offices. They are much more economical in operation than any form of primary cell, inasmuch as there is practically no consumption whatever of the materials in the cell itself, it depending of course for its energy on some outside source. Their ease of manipulation and general cleanliness and reliability are also strong points in their favor.

CHAPTER VII.

CALLING APPARATUS.

So far we have dealt solely with the apparatus by which the actual transmission of speech is accomplished. While these are, of course, the most vital parts of a complete telephone, they would be of little use were not means provided whereby one party might call the attention of another in order to bring about a conversation. Many attempts have been made to devise telephone instruments capable of reproducing speech so loudly that one has only to call into the transmitter in order to attract the attention of a party at the other end of the wire. Such attempts have so far resulted practically in failure, and this is perhaps fortunate, as one of the most convenient features of telephones to-day is that a conversation can be carried on in secrecy, at least so far as the receiving is concerned.

Ordinary vibrating bells, using current derived from a battery, were at first used for calling, and as the battery for operating the transmitters could also be used for this purpose, this plan seemed to offer many advantages. It was found, however, that the amount of energy furnished by a telephone battery was insufficient to operate call-bells at great distances. Of course, practically as high voltage as was desired could be obtained, by using induction coils and causing induced currents from the secondary to pass out over the line. This, however, reduced the current in the same proportion as it raised the voltage, leaving the amount of energy the same.

What is known as a "magneto-generator" is now almost universally used among the independent companies, and until recently by the Bell Company. It is the simplest known form of the dynamo, and consists of an armature of the Siemens type, wound with many coils of fine wire, and so mounted as to enable it to be rapidly revolved between the poles of a permanent horseshoe magnet. Its theory of action is very simple and depends on the principles of magneto-electricity discovered by Faraday and Henry, and pointed out in a previous chapter—that if the number of lines of force passing through a closed coil be varied, currents of electricity will be generated in this coil, the direction

of these currents depending upon the direction of the lines of force and on whether their number is decreasing or increasing.

In Fig. 68 is shown a simple loop of wire, *a*, which may be revolved about a horizontal axis in the field of force of the permanent magnet. The horizontal arrows represent the direction of the lines of force set up by the magnet through the loop. Suppose the loop to be turned in the direction of the curved arrow. When it is in the horizontal position no lines of force will pass through it. As it approaches the position shown by the full line it will include a larger and larger number of these lines. The current induced in the coil will then be in the direction indicated by the arrows, *x*, and will so continue until the loop is in its vertical position. The number of lines passing

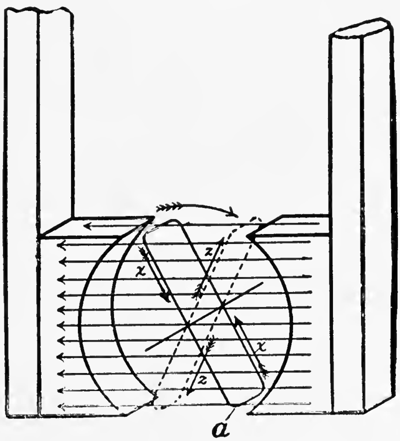


Fig. 68.—Field of Force in Magneto-Generator.

through the loop then begins to decrease, and the current therefore takes the opposite direction, as indicated by the arrows, *z*. The current increases in strength in this new direction until the coil is horizontal. At this point the rate at which the number of lines through the coil is changing is greatest, and the current is therefore a maximum. As the coil passes through the horizontal position the number of lines passing through it begins to increase again. This would cause another change in the direction of the current, were it not for the fact that the direction of the lines of force through the coil also changes. The same events take place during the next half-turn, when the coil is in the position from which it started.

We thus see that the current generated is an alternating one, changing its direction twice during every revolution.

The armature, instead of having a single turn of wire, as in Fig. 68, has a great number of turns of fine wire wound on a cast-iron core of the form shown in Fig. 69. In this figure, *A* repre-

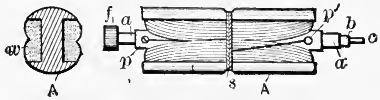


Fig. 69.—Armature of Magneto-Generator.

sents a shuttle-shaped core of cast iron, on which the coils of wire, *w*, are wrapped. One end of the wire forming the coils is fastened to the pin, *p*, which is fastened to and is in metallic connection with the core, *A*. The other end is fastened to the pin, *p'*, which is insulated from the core, but connects with the pin, *c*, projecting from the end of the armature shaft and is insulated therefrom by the fiber bushing, *b*. Projections, *a a*, integral with the core, are turned down to form bearings for the armature. A pinion, *f*, is carried on the end of the shaft, in order

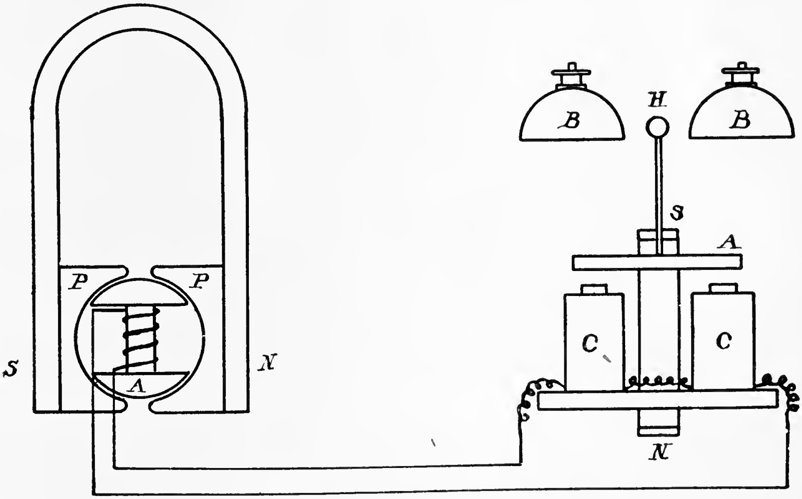


Fig. 70.—Diagram of Generator and Bell.

to transmit to the armature the motion received from a large driving-gear wheel with which it meshes.

A magneto-generator in connection with a call-bell is shown diagrammatically in Fig. 70. To the poles of the permanent magnets, *N S*, of the generator are attached cast-iron pole-pieces, *P P*, bored out so as to allow the armature, *A*, to turn

freely between them. The bearings of the armature are usually mounted on brass plates firmly attached to the ends of the pole-pieces, but not shown in this figure. By means of a crank attached to a suitable gear wheel engaging a pinion on the armature shaft, the armature may be made to turn rapidly.

As the currents generated are alternating, a polarized bell or ringer is needed. *C C* are the two coils of an electromagnet. Pivoted in front of the poles of this magnet is a soft-iron armature, *A'*, carrying a hammer, *H*, on the end of a thin rod extending at right angles from its center. A permanent magnet, *N S*, is so mounted as to magnetize by induction the armature, *A'*, and the cores of the coils, *C C*.

The two poles of the electromagnet will thus have a given

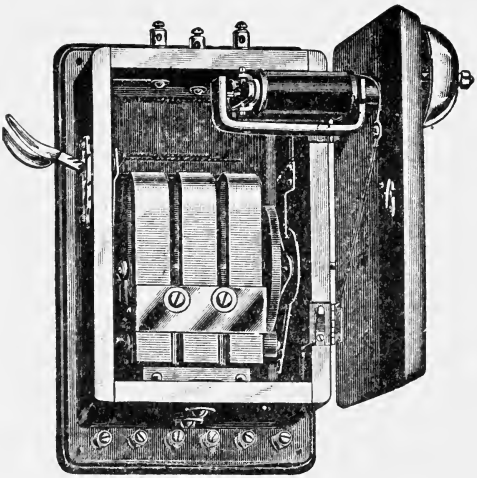


Fig. 71.—Complete Magneto-Generator.

polarity, say, north, while the two ends of the armature will have an opposite polarity, south. As a result, the armature will have a tendency to stick to one pole or the other of the magnets. The two coils are oppositely wound, and when a current passes through them it strengthens the magnetism of one pole and weakens that of the other. The next instant the current reverses, and the strong pole becomes the weaker, and *vice versa*. As a result the armature vibrates with each reverse of current and causes the hammer, *H*, to strike the bells, *B B*. A complete magneto-generator and call-bell, mounted in a box, is shown in Fig. 71. The magnets of the call-bell are mounted on the inside of the lid, the hammer extending through a hole therein to

strike the gongs, on the outside. Fig. 72 shows one of the commercial forms, and a very efficient one, of call-bell mechanism. The forms of ringers used by different manufacturers differ widely; but all depend on the same principles for their mode of action.

The armatures of ordinary hand generators are usually wound to resistances varying from 300 to 650 ohms. The resistance of the ringer coils is usually from 75 to 100 ohms, but is sometimes as high as 5000 ohms, varying according to their use.

The standard generator and ringer for ordinary exchange work are so wound that the generator will ring its own bell, or another like it, through a resistance of 10,000 ohms. Such an outfit is spoken of as a 10,000-ohm magneto, and the 10,000 re-

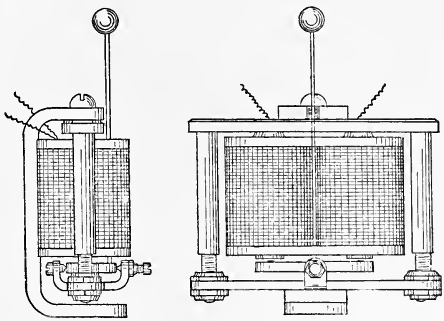


Fig. 72.—Polarized Ringer.

fers *not to the resistance of the bell magnets or the generator armature*, as is often supposed, but to the external resistance through which they will successfully work.

With a given magnetizing force, as for instance that set up by a permanent magnet, the number of lines of force extending from one pole of the magnet to the other will depend on the material between the poles and also on the distance between them. Certain substances, if placed in a magnetic field of force, will have set up in them a vastly greater number of lines of force than would air when subjected to the same magnetizing force. Such substances, in which a given magnetizing force will produce a high degree of magnetization, are said to possess a high degree of permeability. The permeability of a substance is expressed numerically by the ratio of the number of lines of force set up in a given area of it by a given magnetizing force to the number set up in the same area in air by the same magnetizing

force. Thus, if the given magnetizing force sets up 50 lines of force per square inch in air and 20,000 lines per square inch in a piece of wrought iron, the permeability of the iron would be $\frac{20,000}{50} = 400$. The permeability of air is always taken as unity.

Iron, in all of its forms, is by far the most permeable of all metals, and even among the various grades of iron there is a great difference in this respect. Soft wrought iron is much more permeable than cast iron, and cast iron much more so than hard steel.

The great point in the design of magneto-generators, as in fact in dynamo design in general, is to cause as great a number of lines of force as possible to pass through the core of the armature. In the design of ordinary dynamos, where the field is composed of electromagnets, the magnetizing force can be varied almost at will by subjecting the field to the influence of a great number of ampere-turns.

In the design of magneto-generators, however, the strength of the field, when once determined, is, for all practical purposes, invariable, as the strength of the magnets is in no wise dependent on the current generated. Obviously, therefore, the only recourse, in bettering the efficiency of the machine in this respect, is to use as fine a grade of iron as possible in the armature, and to so design it as to present a path of as small resistance as possible to the flow of the magnetic lines. Not enough attention has been given to this point, and often a poor grade of cast iron which was allowed to chill after casting and thus become exceedingly hard, has been used in constructing generator armatures. Fortunately, however, a very hard grade of iron is very difficult to turn in a lathe, especially in this particular form, and this has, indirectly, made some manufacturers seek fairly soft, uniform iron for this purpose.

A cast armature, even though soft, is subject to another objection, in that eddy currents are generated in the core, which, of course, interfere greatly with the efficiency of the machine. In order to do away with both of these objections, some companies are now building laminated armatures, composed of soft sheet-iron punchings about $\frac{1}{16}$ of an inch or less in thickness, clamped together on a central shaft which forms the spindle of the armature. These laminated armature cores are, when completed, of about the same shape as the cast core, and the wire is wound on them in the ordinary way.

After the armature core, however formed, is complete, it

should be thoroughly insulated by paper and cotton cloth, held in place by some insulating adhesive such as shellac, after which it is placed in a winding machine and wound with the required number of turns.

The winding should be of the largest size of wire that will give the desired number of turns, but the wire space should not be so completely filled as to cause the wire to bulge out and strike the pole-pieces of the generator in its rotation, thus wearing away the insulation and frequently breaking the wire itself.

It is a commonly expressed opinion that the turns of wire near the center of the armature coil are of little or no value in producing electromotive force. This, however, is not the case, for the permeability of iron is so much greater than that of air that nearly all of the lines of force due to the permanent magnets of the generator will pass through the shank of the core instead of leaking around through the air space. Of course, in order to pass through this shank, they must also pass through the inside turns as well as those nearer the surface.

The question of permanent magnets is a puzzling one, principally because very little seems to be known concerning the kind of steel best adapted for this purpose. Makers of steel cannot or will not reproduce the quality of samples of steel given them, even after careful chemical analyses. It may be said, however, that a few makers of this steel are able to turn out year after year large quantities of very uniform steel for this purpose, which is capable of giving very satisfactory results. If, however, a sample of one maker's steel is given to another to analyze and reproduce, the result is usually failure. It has been the experience of the writer that the only way to procure a good magnet steel is to test all of the samples obtainable, and, having found a satisfactory steel which the manufacturer is able to produce in large quantities, to stick to that particular grade. It may be said further that the more expensive grades of steel are not by any means capable of producing the best magnets; and frequently where a manufacturer is paying ten to twelve cents per pound for magnet steel, a little experimenting would enable him to find something which would give as good or even better results at from two and one-half to five cents per pound.

The usual method of treating steel for making permanent magnets is to cut it in the desired lengths and, if the cross-section be not too heavy and the form not too complicated, to bend it in a special former while cold. It is then heated to a light cherry-red in a rather slow fire and then grasped by a special pair of tongs

in such manner that it will not bend from the desired shape, and plunged into a tank of cold running water, being kept in violent agitation during the entire time of cooling. All parts of the tongs which come in contact with the magnet during this process should be bored as full of holes as the required strength will permit in order that the water my have free access to all portions of the steel. After the bar has hardened it is magnetized by stroking it several times across the poles of a very powerful electromagnet. The pole-pieces of this magnet should be sufficiently close together to allow one leg of the horseshoe magnet to rest upon the north pole and the other upon the south pole. In some cases the bars are magnetized by inserting them in a solenoid, but probably the best results are obtained by the method of stroking.

Until recently cast iron was the only material used for pole-pieces in magneto-generators, and many good generators are now constructed with that material. A number of generators,

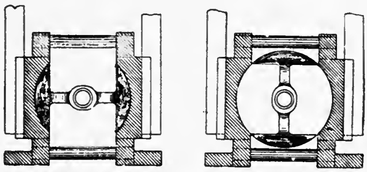


Fig. 73.—Detail of Generator Pole-Pieces.

however, have recently been produced using soft sheet-iron pole-pieces stamped and formed into the desired shape. This forms a cheaper pole-piece than can be procured by the use of cast iron, because the latter must necessarily be subjected to a considerable amount of machine work, such, for instance, as the boring of the concave cylindrical surfaces between which the armature revolves. A point in favor of the cast-iron pole-pieces is that the air gap may be made much smaller because of the greater accuracy of this bore than can be secured by the use of punched sheet-metal pole-pieces. An argument in favor of the latter, however, is that the quality of iron is much better, and this is, of course, of some advantage, but not so great as it would at first appear, because the flow of magnetic lines through these pole-pieces is always in the same direction; and the loss, therefore, due to a lack of permeability in the cast-iron pole-pieces is probably fully offset by the greater cross-section of iron available for the lines to traverse and also by the smaller air gap.

In the construction shown in Fig. 73 the pole-pieces are of

cast iron firmly secured together by shouldered brass rods. After being thus fastened together they are bored out with a special tool, after which the magnets are put in place and clamped by any suitable means. This is a very good, although somewhat expensive, construction when properly done.

The efficiency depends to a considerable extent upon the form of the current wave generated by the machine. This is governed largely by the relation between the width of the pole of the armature and the distance between the flat surface of the generator pole-pieces. In Fig. 73 the best relation between these dimensions is illustrated quite clearly. It will be noticed in the figure at the left that the curved portion of the armature pole exactly corresponds to the concave portion of the pole-pieces, while in the figure at the right, which shows the armature in a different position, the poles of the armature are just sufficient in width to bridge across the space between the pole-pieces without overlapping.

The sine wave has been found to be most efficient in the ringing of magneto-bells, especially on lines of considerable length and possessing a high degree of self-induction and capacity; and the relation between the armature poles and the pole-pieces shown in the above figure gives the nearest approximation to this form of wave. Where the armature poles do not fill the space between the pole-pieces, the current curve will have four distinct humps in each complete cycle. There will be a break in the magnetic circuit just as the armature pole leaves the pole-piece on one side, which will cause a sharp fluctuation in the electromotive force; and another sharp fluctation will occur immediately after, when the opposite points of the armature poles approach the corners of the pole-pieces. These two fluctuations will occur twice in each cycle. When the armature poles are so wide as to overlap, when in the position shown in the right-hand portion of Fig. 73, the wave is flattened unduly and does not, therefore, give as high an electromotive force as could otherwise be obtained.

The effective pressure of the ordinary magneto-generator, when rotated at the ordinary speed by hand, is from 65 to 75 volts, and it may be made, of course, higher or lower to meet certain requirements by winding with a greater or less number of turns or by gearing the armature so as to rotate with greater or less speed.

Some telephone lines, as for instance party lines, using a large number of instruments in series, require magneto-generators

capable of producing a very high electromotive force in order to successfully overcome the great resistance offered. Inasmuch as all of the bells are in series, the current required is not large. In a bridged line, however, where all of the ringer magnets are connected across the line in parallel, the current required is heavy, while the voltage need not, as a rule, be so high. In long lines of this latter type using a high-resistance wire, it becomes necessary to develop enough pressure to overcome the resistance of the line wire in order to ring the bell at the farthest end, and also a sufficient current to pass in multiple through all of the ringers. In this case a rather high voltage is required and a heavy current, so that the total amount of energy is large and cannot be effective merely by winding the instrument to a higher resistance. In generators of this type it is customary to use heavy and very powerful permanent magnets and to exercise the greatest care in the construction to produce the highest efficiency.

The construction of the polarized call-bell, or ringer, is a matter requiring no less attention to detail than that of producing an efficient generator. The old form of ringers, using a cast-iron frame polarized by small electromagnets, was subject to very grave defects. The frame became readily polarized in one direction or the other, due to the passage of a heavy current through the magnets, and would thus give the armature a set to one side or the other, which frequently succeeding currents of a weaker nature could not overcome. This, with the fact that with every reversal of the current the entire magnetic field set up through this heavy mass of poor-quality iron had to be completely reversed, was a point rendering the construction of an efficient ringer almost an impossibility. The tendency in the present form of ringers is to make a magnetic circuit which is subjected to the changes due to the magnetizing force as short as possible and to make the magnetic circuit of the very best possible material. Swedish or Norway iron, cold drawn and annealed, has been found to meet these requirements most perfectly. The sticking of the armature to one pole or the other is further prevented by the interposition of a thin sheet of non-magnetic material, usually copper, between the faces of the armature and the pole-pieces. Sometimes this is accomplished by inserting a small rivet either into the center of the pole-piece or into the armature face itself.

The length of the rod carrying the hammer plays a considerable part in the sensitiveness of the bell. A long rod will secure for the hammer a long, and therefore powerful, stroke, but the

sensitiveness is correspondingly reduced. On the other hand, a short rod will produce a short and comparatively weak stroke, but the bell will be more sensitive than with the long rod.

Other points in the design of magneto-generators and ringers will be taken up in a subsequent chapter on Commercial Forms of Magneto-Bells. Before considering these in detail, however, certain other accessories must be described.

CHAPTER VIII.

THE AUTOMATIC SHUNT.

On account of the high resistance of the generator armature and its great retarding effects, it is desirable to have it shunted out of the line when the generator is not in use. Especially is this desirable on party lines where two or more instruments are used on a single line. To accomplish this many devices have been used, both automatic and manual. The automatic devices have now almost entirely supplanted the manual, as the latter were never satisfactory, owing to the inability of ignorant and careless persons to properly manipulate them. Many styles of these automatic shunting devices have come into general use, the ones shown and described being typical. Referring to Fig. 74,

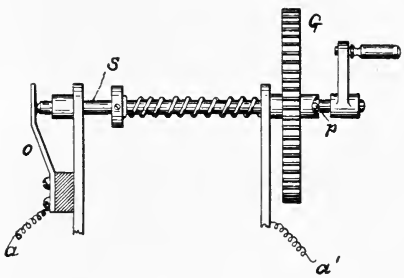


Fig. 74.—Western Electric Armature Shunt.

which shows the shunt used by the Bell Company, the gear-wheel, *G*, is mounted on the crank-shaft, *S*, and is free to turn thereon through a small portion of a revolution. Terminals, *a a'*, are connected to the terminals of the armature winding.

When the generator is at rest a current coming over the line will pass from *a'* through the crank-shaft and out through the spring, *o*, to the terminal, *a;* this path being of almost no resistance, while that of the armature winding is large. When the crank is turned, however, the pin, *p*, rides out of the notch in the hub of the gear-wheel and in so doing pulls the shaft out of contact with its spring, *o*, thus breaking the low resistance path or shunt around the armature, and leaving the latter effectively in the line.

In Fig. 75, *A* is the core of the armature, *G'* its pinion, and *w* a diagrammatic representation of the winding. While at rest current from the line, instead of passing through the coil, *w*, will take the path from *a'* through the core, *A*, to the spring, *S*, thence to pin, *p*, on which *S* normally rests and thence out through pin, *c*, to the terminal, *a*. When the armature is revolved the cen-

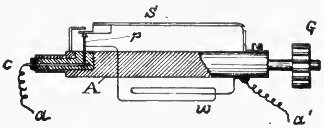


Fig. 75.—Centrifugal Armature Shunt.

trifugal force of the end of spring, *S*, causes contact to be broken between it and pin, *p*, which opens the shunt around the armature winding.

In Fig. 76, *G* is the large gear-wheel and *G'* its pinion on the armature shaft. The low-resistance path around the armature is from point *a* through spring, *S'*, screwed on the inside of the generator box, through spring, *S*, gear, *G*, to the frame of the machine and out at *a'*. When the crank is turned, the collar, *c*,

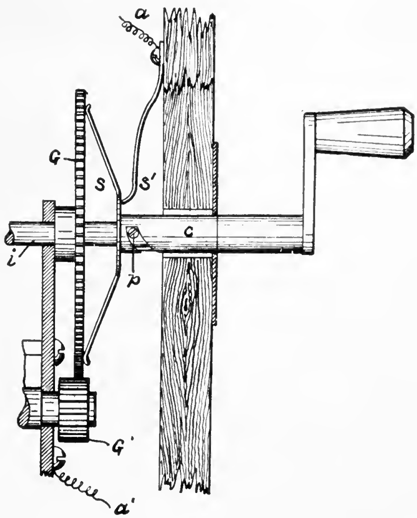


Fig. 76.—Western Telephone Construction Co. Armature Shunt.

which is loose on the shaft, *i*, but rigid with the crank, forces the spring, *S*, away from the spring, *S'*, by virtue of the pin, *p*, mounted on the shaft, *i*, engaging the spiral slot in the collar, *c*.

In the later forms of this shunt, which is that of the Western Telephone Construction Company, a disk collar pressed from sheet brass is interposed between the springs, *S* and *S'*, thus affording a better contact surface for the spring, *S'*.

A shunt device recently put on the market by the Sterling Electric Company is shown in Fig. 77. The shunt mechanism is operated by the crank-shaft, which carries the large gear-wheel. This shaft turns in a hollow sleeve, 24, which is journaled in the brackets, 25, mounted on the end plates of the machine. A pin, 27, fixed in the crank-shaft, 23, engages a diagonal slot, 26, in the sleeve, 24. This pin is held at one end of the slot by the spring, 28, which is coiled around and fastened to the sleeve, 24.

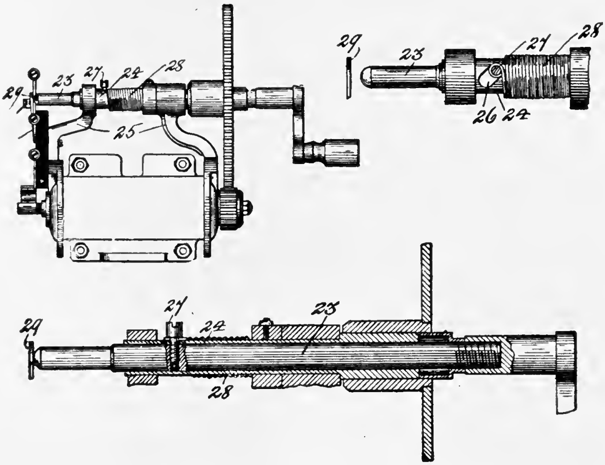


Fig. 77.—Details of Cook Armature Shunt.

When, however, the crank-shaft is rotated, the pin, 27, rides against the side of the slot, 26, until it assumes the position shown in the upper right-hand portion of the figure, after which the sleeve and gear turn with the shaft. This causes the crank-shaft, 23, to break contact with spring, 29, and thus break the shunt around the generator.

Another shunt, dependent on an entirely different principle very ingeniously applied, is that used by the Holtzer-Cabot Company. A small cylindrical case of brass is mounted directly on the projecting portion of the armature shaft, and is in metallic contact therewith. The insulating pin with which the other terminal of the armature winding is connected projects into the chamber formed by this case; but does not come into metallic contact with the casing nor the armature shaft itself. The chamber is then

partially filled with small bits of metallic wire which normally form a connection between the central pin and the casing itself, thereby forming a short circuit or shunt around the armature winding. When, however, the armature is rotated, the centrifugal force, due to the rotation acting upon the bits of wire, causes them to fly to the outer portion of the casing, thus breaking the contact with the central pin and removing the shunt from the armature. This is probably the simplest shunt on the market, and should prove reliable. In order to prevent corrosion of the parts, the casing and the small particles of wire are silver-plated.

Still another shunt of new design is that used by the Williams Electric Company on their new generators. It is shown in Fig. 78.

In this figure the crank-shaft, *s*, is tubular and incloses the shaft, *s'*, on which the gear-wheel is mounted. The crank-shaft is

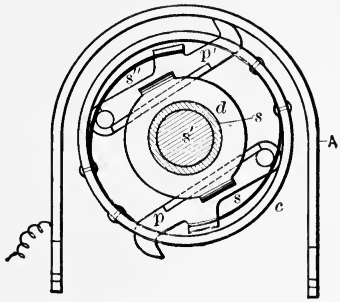


Fig. 78.—Williams Armature Shunt.

capable of a slight rotation before the gear-shaft is moved, such rotation, or what may be termed lost motion, being consumed in depressing two springs, *s s'*, which actuate levers, *p p'*, within the cup-shaped piece, *c*, mounted on the crank shaft. One or both of these levers makes contact with the arched metallic strip, *A*, insulated from the frame of the generator, while the crank is at rest. As soon, however, as it is turned the lost motion is taken up in removing the levers from contact with this arch. This breaks the shunt which is formed from the frame of the machine, which is in contact with one terminal of the armature winding, through the levers to the arched strip, which is connected by a wire, to the spring at the right-hand portion of the generator, which bears upon the armature spindle.

CHAPTER IX.

THE HOOK SWITCH AND CIRCUITS OF A TELEPHONE.

So far we have considered the talking apparatus and the calling apparatus separately. It is obvious that inasmuch as these are used alternately, some means is necessary for switching one or the other into the circuit. As an instrument must, when not in use, be ready to respond to a call, the call-bell must, of necessity, be normally left in the line; and further, as the resistance and self-inductance of the call-bell magnets would be detrimental to the transmission of talking currents, the call-bell must in most cases be switched out of the line when the talking instruments are in use.

At first, hand switches were used to accomplish this result, and even before the adoption of the battery transmitter the instruments were provided with ordinary two-point hand switches, so arranged as to alternately close the line circuit through two branches—one containing a call-bell and generator, and the other the magneto-telephone. It was soon found necessary to make this switch as nearly automatic as possible, as careless or ignorant users would frequently leave it in the wrong position. To attain this end, the switch lever was so designed as to be held by the weight of the receiver in contact with a terminal of the calling circuit, but when released therefrom to be moved by a spring into contact with the talking circuit terminal. Soon after, battery transmitters having come into general use, it became necessary to provide means for opening and closing a local circuit containing the local battery, the primary of the induction coil, and the microphone transmitter. This was done in order to have the battery in use only when the telephone instrument was being used, and was accomplished by the addition of a single contact point with which the hook made contact when released from the weight of the receiver.

Fig. 79 shows the circuit of an ordinary telephone instrument. The hook, *H*, is shown in its depressed position as though under the weight of the receiver. In this position all talking circuits are inoperative, being open at the points, 1 and 2, and are for that reason represented by dotted lines. A calling current from some

other station coming over line wire, *L*, would pass through wire, *a*, to the generator, *G*, thence through the windings of the call-bell magnet, *C*, to the contact point, 3, through the lever of the hook switch and out through line wire, *L'*, or to ground, in case

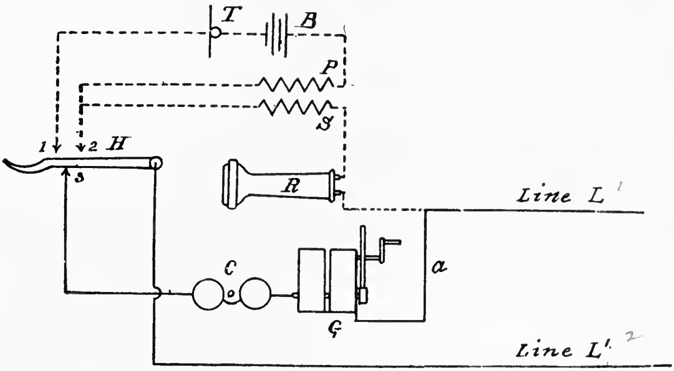


Fig. 79.—Telephone Circuits, Hook Down.

no return wire is used. This current will ring the bell. To obviate the necessity of this current passing through the armature winding of the generator, a shunt should be provided, as described in the last chapter. When the instrument is used for sending a call the crank of the generator is turned, automatically breaking the shunt around the armature and sending the current out over

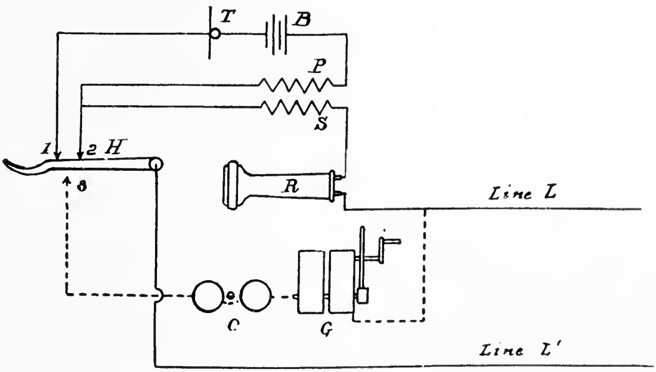


Fig. 80.—Telephone Circuits, Hook Up.

the line through the call-bell magnets of this instrument to those of the distant station.

In Fig. 80 the hook is shown in its raised position, as when released from the weight of the receiver. The circuit through the generator and call-bell is inoperative, being open at the

point, 3, and is therefore shown dotted. The local circuit containing the primary winding, *P*, of the induction coil, the battery, *B*, and the transmitter, *T*, is closed by the switch lever making contact with the points, 1 and 2. Current therefore flows in this circuit, and variations in the resistance of the microphone, *T*, cause corresponding variations in this current, which induce currents in the secondary winding, *S*, of the induction coil. These currents pass from the secondary coil to the point, 2, thence through the switch lever to line. *L'*, to the instrument at the other end of the line, back by line, *L*, and through the winding of the receiver, *R*, to the secondary coil, *S*. An incoming current from

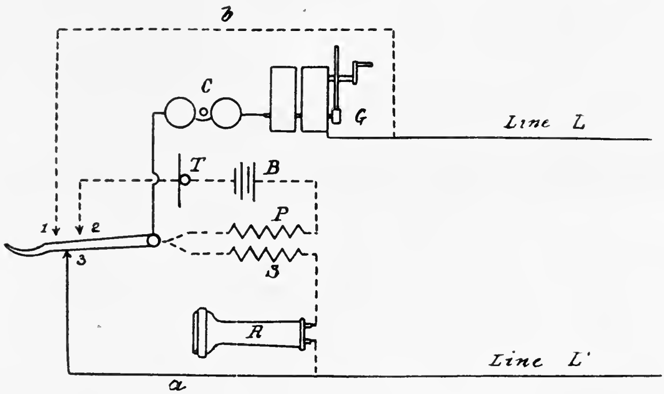


Fig. 81.—Telephone Circuits, Hook Down.

a distant station follows the same path, and causes the diaphragm of the receiver to reproduce sound.

In Figs. 81 and 82 are shown circuits and apparatus for accomplishing the same results, but in a slightly different way. It will be seen that the circuit through the generator and call-bell, and that through the receiver and secondary winding, are permanently closed, and are unaffected as to their continuity by the position of the hook switch. In Fig. 81 the hook is depressed, thus rendering operative the calling apparatus. The circuit through the instrument is now from line, *L*, to the generator, *G*, thence through the call-bell magnets, *C*, through the switch lever to the point, 3, and by way of wire, *a*, to the line wire, *L'*. A current from the generator, *G*, of this station or another would pass through the secondary coil, *S*, and the receiver, *R*, were it not for the fact that the wire, *a*, affords a path of practically no resistance, thus short-circuiting the receiver and secondary.

In Fig. 82 the hook switch is in the talking position and the

generator, G, and the call-bell, C, are rendered inoperative by virtue of the low-resistance path, b, being closed around them. The circuit through the instrument is now through the wire, b, contact point, 1, lever, H, secondary coil, S, and receiver, R. In the arrangement shown in Figs. 81 and 82 the local circuit is operated in the same manner as that shown in Figs. 79 and 80. The practice of leaving both the calling and the talking circuits permanently closed and of shunting one or the other out of the circuit is a good one, for if the hook does not make proper contacts the apparatus is still operative, although its efficiency is impaired.

Although the automatic switching apparatus is very simple, much care is necessary in its design and construction. The energy available for the operation of the switch is limited to that due to the attraction of gravity on the receiver, and it becomes somewhat difficult to so arrange the contacts that they will be

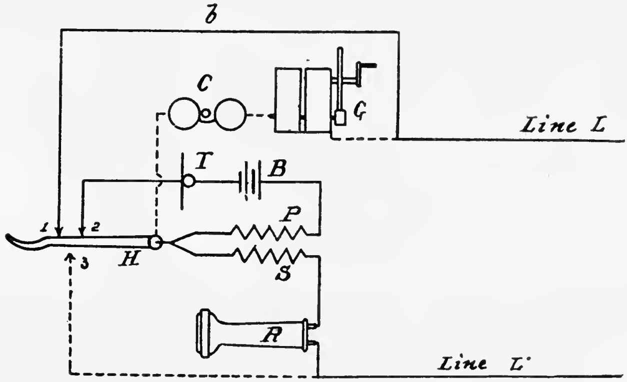


Fig. 82.—Telephone Circuits, Hook Up.

firmly and positively made, and surely broken at the proper time. For this reason all the points of contact are preferably provided with platinum tips to prevent corrosion, and, if possible, a slight sliding action at the point of contact should be obtained. A sliding contact tends to clean the points and at the same time prevents particles of dust from keeping the two apart. Too much sliding action is, however, worse than none, as it is sure to cause cutting. The springs for restoring the lever and those serving as contacts should be so arranged that no movement of which the lever is capable will strain them beyond their elastic limit or to such a degree that they will eventually lose their tension or break. It is bad practice to have the same part of a contact slide alternately over a conducting material, as of brass, and

an insulating material, as of hard rubber, as small particles from either surface are sure to be carried upon the other surface, thus forming a partial electrical connection on the insulating surface and a defective connection on the brass or metal surface. Where a sliding contact is used much trouble is often caused by the cutting of the two surfaces. The extent of this cutting, even where the pressure is very light and the movement very limited, is often astonishing.

In Fig. 83 is shown the hook switch now almost universally used by the Bell Telephone Company, and known as the "Warner Switch." The hook lever is pivoted to a bracket by a screw as shown, and is provided with a lug, *f*, and a strip of insulating material, *g*, on its short arm. On the under side of the lever is an insulating pin, *h*, and a contact point, *i*. A spring screwed to the generator box under the lever by the screw, *b*,

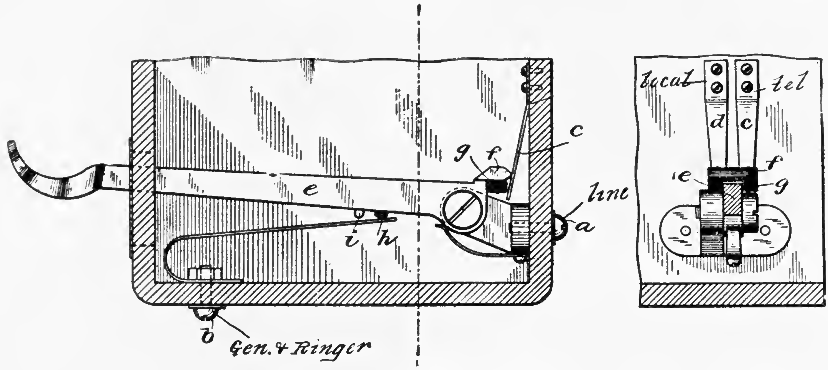


Fig. 83.—Warner Hook Switch.

bears alternately upon the insulating pin, *h*, and the contact point, *i*, and tends to press the lever into its elevated position. Springs, *c* and *d*, screwed to the side of the generator box bear alternately upon the insulating piece, *g*, and the conducting lug, *f*, according to whether the lever is depressed or elevated. The spring, *c*, is connected through the secondary winding of the induction coil and the receiver to one side of the line. The screw, *b*, is connected through the calling apparatus to the same side of the line. The binding screw, *a*, connected with the lever, *e*, forms the terminal of the other side of the line. The local circuit terminates on one side in the spring, *c*, and on the other side in the spring, *d*. When the hook is depressed, point *i* is connected through the lower spring with the screw, *b*, and the

calling circuit is complete. Both the local circuit and the line circuit through the talking apparatus are broken at springs, *c* and *d*. When the hook is elevated, the calling circuit is broken at the point *i*, and the local and line circuits are completed by the springs, *c* and *d*, and the lug, *f*.

This hook switch is as perfect as any on the market, and a study of it is interesting as showing a nicety of detail that can be appreciated only by those who have had practical experience in telephony.

When platinum is not used on hook-switch contacts, it is a matter of absolute necessity to have rubbing contacts, and cutting may be reduced to a minimum by making the contact surfaces of dissimilar metals. German-silver springs bearing on brass contacts form as good a combination as can be obtained without the use of platinum. The lever of the hook nearly

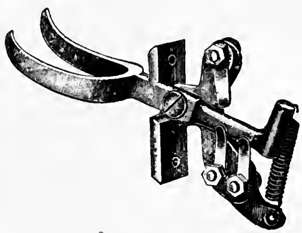


Fig. 84.—Short Lever Hook Switch with Poor Contacts.

always forms one branch of the circuit, and in no case should the contact through the pivot screw be depended on for conductivity. A good plan is to form a soldered connection between the lever and base, by means of a short spiral of flexible wire, soldered at one end to the lever and at the other to the base, the connection being made at points where the relative motion between the two parts is a minimum.

Fig. 84 shows a common type of switch which should be guarded against. The short contact springs have little flexibility, and cutting between them and the hook lever soon sets in. The friction soon becomes so great that the lever will stick in one position or the other, and neither the weight of the receiver nor the strength of the retractile spring is sufficient to move it.

Figs. 85 and 86 show two hook switches manufactured by the Holtzer-Cabot Electric Company. The former is adapted for mounting in the bottom of the generator box, in front of the generator, and the latter on the side of the box, above the generator. These hooks have the advantage of being self-con-

tained, and depend on a rather heavy sliding contact obtained by the use of long flexible springs.

The diagrams of circuits shown in Figs. 79, 80, 81, and 82 were

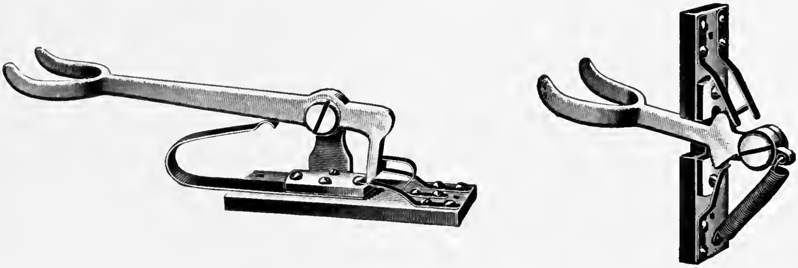


Fig. 85 and 86.—Long and Short Lever Hook Switches.

somewhat simplified in order to render clearer the circuits. In Fig. 87 is shown the circuits of a complete telephone set, the connections being arranged as in practice. It is customary to mount the generator, *G*, polarized bell, *P*, and hook switch all in one box. In order to facilitate the work of making connections

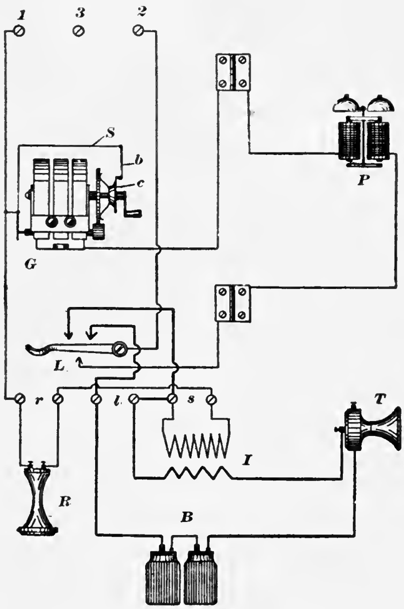


Fig. 87.—Complete Circuits of Series Telephone.

between the parts contained in the generator box and the other parts, *i. e.*, the transmitter, induction coil, receiver, and batteries, the terminals of all the circuits in the box are brought out on

binding posts on the top and bottom of the box. The binding posts, 1 and 2, on top of the box are for attaching the line wires. These form the terminals of the instrument as a whole. The center binding post forms the ground terminal of the lightning arrester, and has no connection within the box.

The six binding posts at the bottom of the generator box are in three pairs, *r*, *l*, and *s*. The pair, *r*, form terminals for attaching the receiver cord. The two posts forming pair, *l*, are for the local circuit, containing between these posts the battery, *B*, the transmitter, *T*, and the primary of the induction coil, *I*. Between the right-hand pair of posts, *s*, is connected the secondary of the induction coil, *I*. The bell, *P*, is mounted on the door of the box, connection to it being made through the hinges.

The connections of the automatic shunt are clearly shown in this figure. Normally a short circuit exists around the generator, through the wire, *S*, spring, *b*, disk, *c*, and the frame of the machine. This is broken between the spring, *b*, and disk, *c*, when the generator is operated as already described.

Fig. 88 is a view of a complete instrument, showing quite clearly the external connections of the generator box. In this, posts, *E* and *C*, are the line terminals, and *D* the ground post for the lightning arrester. The two left-hand binding posts on the bottom of the box form terminals for the receiver cord, as shown. The two center posts, *I* and *H*, correspond with the pair of posts, *l*, in Fig. 87. The curled wire from *I* passes through the back board of the instrument and to one terminal of the battery in the battery box below. The post, *H*, is connected by a similar wire to the binding post, *N*, on the transmitter base, from which the circuit may be traced through the primary of the induction coil, thence to the metallic portion of the transmitter arm and base to the carbon electrode of the transmitter, then through the transmitter and back by a flexible cord along the side of the arm, which connects with the lower post, *L*, on the base. This post is then connected by a curled wire passing through the back board to the remaining terminal of the battery.

This instrument, which is made by the Western Telephone Construction Company, possesses a unique form of switch hook. The hook lever is journaled in the side of the box, and is provided with a short, downwardly bent lever, carrying on its inner end a small anti-friction shoe. Against this shoe bears the long heavy spring, *O*, screwed to the inside of the generator box. The strength of this spring, which presses toward the left, is

sufficient to keep the hook elevated while it is not supporting the receiver. The weight of the receiver, however, forces the short arm of the lever toward the right, moving the spring, *O*, with it.

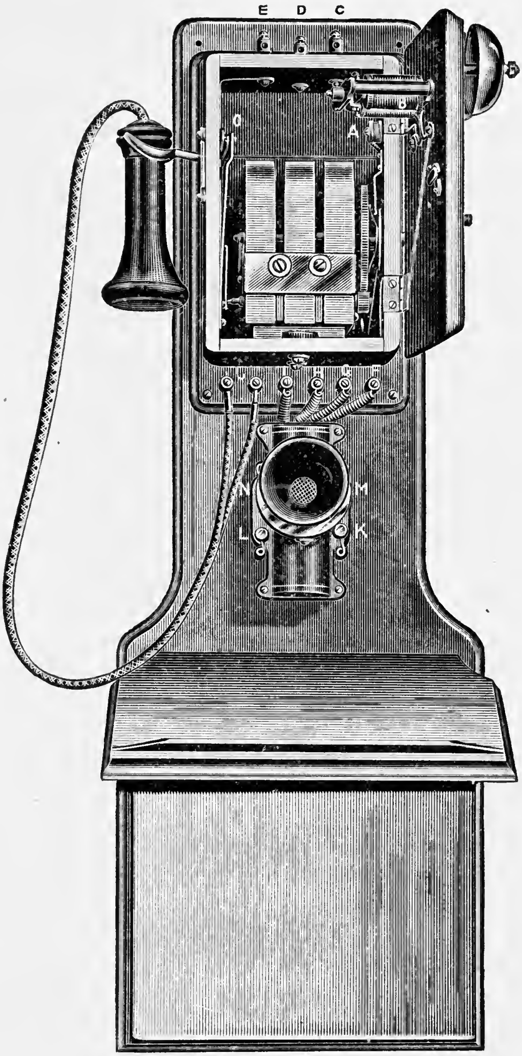


Fig. 88.—Complete Telephone Instrument.

The changes of circuit are accomplished by the movements of this spring, and not by the lever itself, which forms no part of the circuit. The contact springs with which this main spring engages are long and flexible, and are mounted horizontally on

the inside of the box. These springs are platinum-pointed, as is also the main spring, so that the contacts are made and broken in a reliable manner. The old forms of this hook switch were very faulty. The anti-friction shoe, and the platinum contacts, however, together with the improved design of the springs, have rendered it thoroughly reliable.

The details of the generator and ringer of this instrument will be described in the next chapter. Another feature of interest in this set is the small coil, *A*, not shown in the diagram of circuits. This also will be discussed in a subsequent chapter.

The circuits of a bridging-bell instrument are shown in Fig. 89.

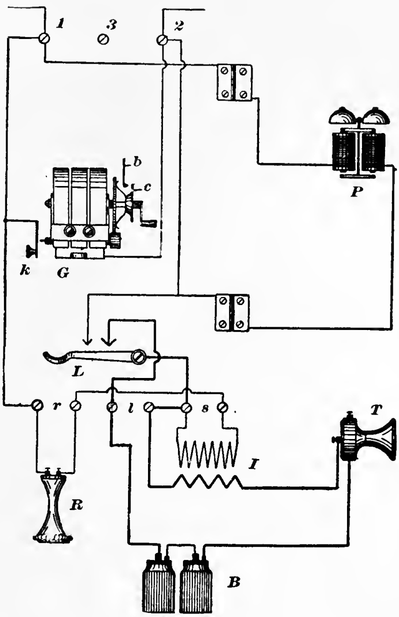


Fig. 89.—Complete Circuits of Bridged Telephone.

This instrument is especially adapted to use on party lines, but is also used to a large extent in general exchange work.

In this instrument the call-bell, *P*, is *permanently* bridged across the two sides of the line between the binding posts, 1 and 2, and its magnets are made of high *resistance* and *retardation*. A little consideration will show that the bell circuit is not affected by the position of the hook lever, there being no lower contact to the switch. The generator, *G*, is in a second bridge circuit, which is normally open, but closed when the generator is operated. The talking circuit, containing the receiver, *R*, and secondary winding of

the induction coil, *I*, forms a third bridge circuit, which, like the generator circuit, is normally open.

The telephone circuit is automatically closed when the receiver is removed from its hook for use, and this operation also closes the local circuit, containing the primary of the induction coil, *I*, the local battery, *B*, and the transmitter, *T*. The talking circuits are identical with those in Fig. 87. In order that there shall not be an undue leakage of the voice currents through the permanently bridged call-bell circuit, the magnets of these call-bells are wound to a high resistance (usually a thousand ohms) and are also constructed in such manner that they will have a high coefficient of self-induction.

The closing of the generator bridge upon the sending of a call may be accomplished manually, as with the key, *k*. It is usually

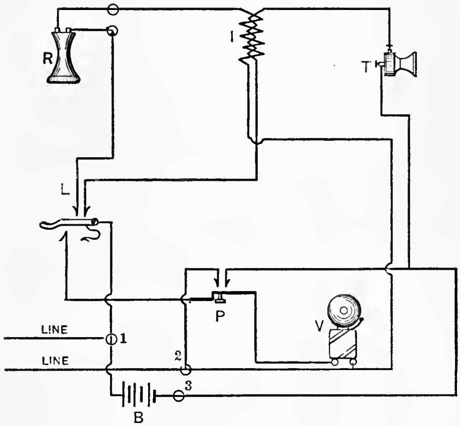


Fig. 90.—Circuits of Battery Call Instruments.

done automatically, however, by a device similar to the automatic shunt used in the regular instruments. Thus, if the wire leading from binding post, 2, in Fig. 89, were led to the spring, *b*, instead of to the frame of the generator, and the binding post, 1, permanently connected to the armature spindle pin, it is evident that the inward movement of the disk, *c*, caused by turning the generator crank, would accomplish the same result as pressure on the key, *k*, and with the advantage of not requiring the volition of the operator.

The specific arrangement of circuits shown in Fig. 89 and their use in multiple on party lines is patented by Mr. John J. Carty, engineer of the New York Telephone Company. The operation

and design of this instrument will be considered at greater length under the head of Party Lines.

The circuits of a battery call set are shown in Fig. 90. In this 1 and 2 are the line binding posts, and 3 a post forming one terminal of the local battery, the post, 1, also serving as a battery terminal. When the hook, *L*, is depressed by the receiver the circuit passes from line post, 1, through the hook lever, back contact of push-button, *P*, vibrating call-bell, *V*, and to line post, 2. The instrument is therefore ready to receive a call. To send a call, battery, *B*, is connected between the line posts by pressing the button, *P*; the circuit being traced from post, 1, through battery, *B*, and the two upper contacts of the button, to binding post, 2. The talking circuits are closed in the ordinary manner by the raising of the hook lever.

Fig. 91 shows a type of telephone set which is becoming

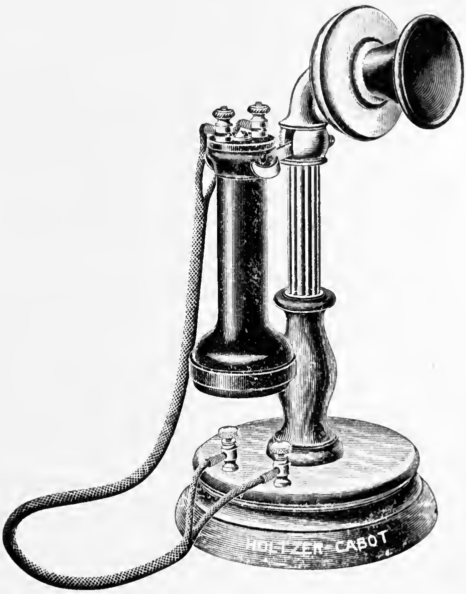


Fig. 91.—Desk Telephone Set.

very popular for business men who do not desire to leave their desks in order to use the telephone. The particular set illustrated is made by the Holtzer-Cabot Company. The transmitter is of the granular-carbon type mounted on a handsome, nickel-plated and polished wood stand, as shown. One terminal of the transmitter is formed by the frame itself, while the other terminal is carried down the inside of the tube, or standard. The lever of

the hook switch is pivoted at its end in an enlargement of the standard and actuates a slender rod which passes down into the base, where it engages the switch lever. This lever is pivoted on a separate bar, mounted on a fiber block and acted upon by a spiral spring in such a manner as to press upward against the vertical rod, thus tending to raise the hook. In this position a knife edge, carried on the switch lever in the base, presses against the two springs, which form, respectively, terminals of the primary and secondary talking circuits. When the hook is subjected to the weight of the receiver the switch lever is depressed by the rod against the tension of the spiral spring, thus breaking connection with the two springs of the talking circuit and making connection with a spring forming the terminal of the calling circuit. The induction coil is mounted in the base. This apparatus

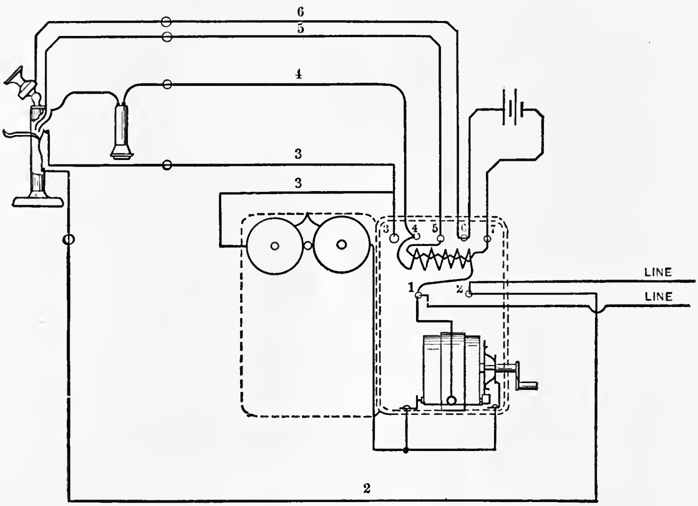


Fig. 92.—Circuits of Comple Desk Set.

may be used in connection with a magneto-generator and call-bell, which are usually placed under the desk or at some point where the generator crank is within easy reach of the user, or in connection with a battery-call outfit, in which case the circuits would be similar to those shown in Fig. 90.

Fig. 92 shows the circuits of an apparatus similar to this, manufactured by the Western Telephone Construction Company. Seven binding posts are arranged in this set on the upper side of the magneto-box, to which all terminals from the various pieces of apparatus are run. 1 and 2 form the line binding posts, and 6 and 7 the battery binding posts, the other terminals being con-

nected as shown. Inasmuch as the induction coil in this set is mounted in the generator box, it becomes necessary for five different conductors to run from the generator box to the desk stand. These conductors are constructed in the same manner as an ordinary receiver cord, there being five strands instead of two. In this latter set the hook switch is of the same type as previously described in connection with Fig. 88, but is so modified as to enable it to be placed in the vertical standard supporting the transmitter. It is platinum-pointed and, as recently modified, should prove reliable.

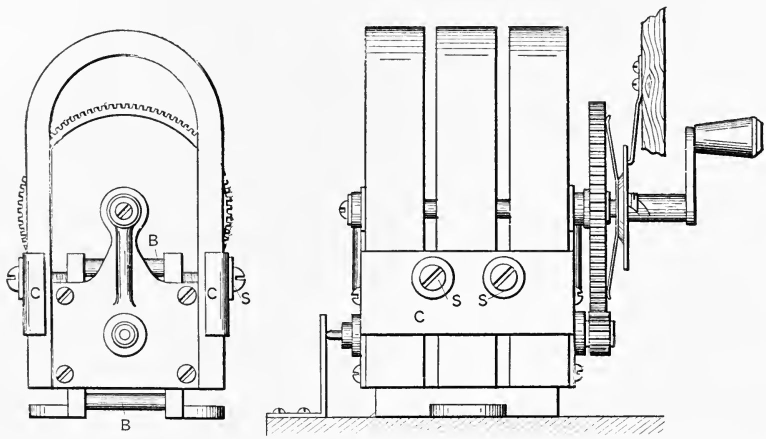
The connections in a telephone cannot be too carefully made. All possibility of two wires coming into accidental contact should be carefully avoided. All joints should be soldered, without the use of acid. Where connection is made under the head of a screw passing through the wood of the box, means must be taken to prevent the loosening of the connection due to shrinkage of the wood. If possible, the connection should be soldered; if not, a spring washer may be used.

CHAPTER X.

COMMERCIAL CALLING APPARATUS.

THE combination of a magneto-generator and a polarized bell or ringer, mounted in a suitable box, is usually termed a magneto-bell. The hook switch, from the fact that it is usually mounted in the generator box, is often counted as a part of a complete magneto-bell. Owing to the lively competition between various manufacturers, and also to the increasing demands for good service on the part of the public, great improvement has been made in this line of work during the last few years. This chapter will be devoted to a consideration of some of the more approved forms of this very important part of telephone equipment.

The details of the Western Telephone Construction Company's large generator for heavy work are shown in Figs. 93, 94, and 95.



Figs. 93 and 94.—Details Western Telephone Construction Co. Generator.

This instrument is very similar to the one used by the Bell companies. In it the pole-pieces are of cast iron, riveted together by means of the shouldered brass rods, *B B*. After this they are bored by a special tool to the required internal diameter to receive the armature. The core of the latter is of cast iron and is shown in Fig. 95, being accurately turned to fit between the pole-

pieces. The bearing plates are of cast brass with a shoulder also turned to fit between the pole-pieces so as to be self-centering when secured in place. They are each fastened to the ends of the pole-pieces by four screws, as shown. The gears are cut from heavy cast brass, the large gear being mounted on a shaft journaled in the same bearing plates as the armature itself.

The magnets are bent cold from $\frac{3}{8}''$ x $\frac{7}{8}''$ magnet steel, and are secured in place by clamping plates, *C C*, and screws, *S S*, the latter passing between the magnets and into the pole-pieces. This generator, while it embodies no new or radical features, is well made and generally satisfactory. It would give better results, however, were the armature of smaller diameter. The air gap in machines of this type may be reduced to less than $\frac{1}{100}$ of an inch without endangering the smooth running of the armature. The automatic shunt already referred to is shown to better advantage in these figures.

The polarized bell used with the later types of this instrument is shown in Fig. 88. The two coils, *B*, are parallel, and attached

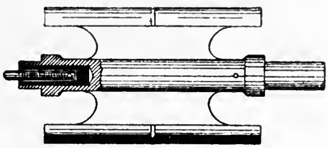


Fig. 95.—Armature Core of Generator.

at one end to a soft-iron yoke, the ends of which extend beyond the coils, to receive the two round bar-magnets, which polarize the frame of the bell.

On the projecting ends of these two permanent magnets is mounted a second yoke bar of soft iron, on which is adjustably mounted the bracket in which the armature is pivoted. The two magnets have their forward ends of one polarity and their rear ends of the other; and, together with the two yokes, form a rectangle, one of the yokes being of positive polarity, the other negative. In this rectangle are mounted the coils and armature of the ringer, which operate in the usual manner by the alternating ringing currents.

The Holtzer-Cabot Electric Company are manufacturing an excellent magneto set, the generator and ringer of which are shown in Figs. 96 and 97. The end plates in which the generator armature is journaled are of cast brass and are screwed directly to the cast-iron pole-pieces, the ends of which are flanged and machined so as to fit accurately. The armature core is of soft sheet-iron

laminations. The punchings forming the core are clamped together on a steel rod, which therefore serves as the armature shaft. The drive-wheel is mounted in a long bearing, adjustably secured to an extension on the right-hand end plate. This company uses two forms of driving gear, one the regular gear-

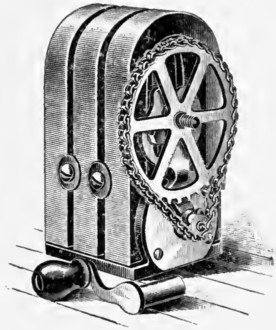


Fig. 96.—Holtzer-Cabot Generator.

wheels and the other the chain and sprocket mechanism shown. It seems to prefer the latter, which, it must be said, when provided with a steel chain, runs very easily and noiselessly. This generator is provided with the centrifugal shunt described in Chapter VIII., mounted directly on the armature shaft, the whole forming a very efficient combination. The generators for bridging-bell service manufactured by this company are of a similar type, but provided with four magnets instead of three, and a correspond-

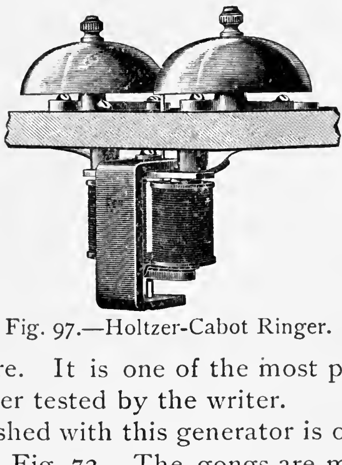


Fig. 97.—Holtzer-Cabot Ringer.

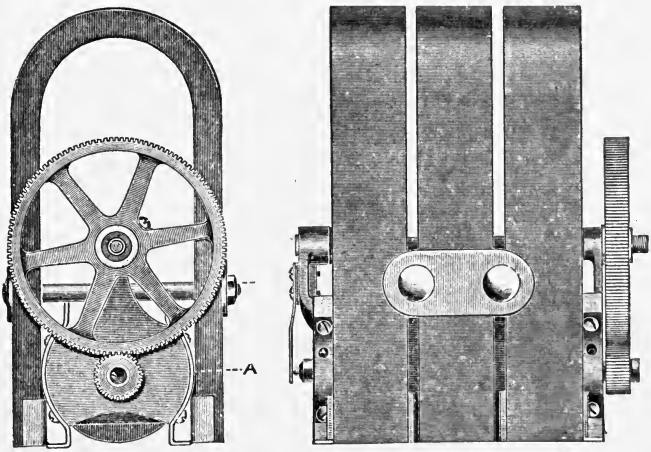
ingly long armature. It is one of the most powerful generators for this purpose ever tested by the writer.

The ringer furnished with this generator is of the same general type illustrated in Fig. 72. The gongs are mounted on adjustable standards pivoted at their upper ends, and each held by a screw engaging a slot in their lower ends.

The Williams-Abbott magneto-bell is shown complete in Fig. 98 and in detail in Figs. 99, 100, and 101. In this the pole-

Fig. 98.—Williams-Abbott Magneto-Bell Complete.

pieces of the generator are stamped from soft sheet iron and fastened to the circumferential edges of the end plates by four screws at each end. The edges of the end plates are of the proper curvature to maintain the inner surfaces of the pole-pieces in their proper relation to the armature. The lower edges of the



Figs. 99 and 100.—End and Side Views Williams-Abbott Generator.

pole-pieces are bent back and up so as to form a seat for the permanent magnets, which are secured in place by two bolts passing, respectively, between the two outside and the center magnets. The gear-wheels in this instrument are cut with a very wide face to prevent wear.

The ringer shown in Fig. 101 is unique and embodies several desirable features: The two ends of the U-shaped permanent magnet are of the same polarity—say, south—and its middle is of the opposite polarity. (Hence the name tripolar, frequently applied to this ringer.) The two coils are mounted on the iron cross bar, extending between the legs of the permanent magnet. The poles of these electromagnets therefore partake of the polarity of the permanent magnet ends,—that is, south,—while the armature, supported from the center of the permanent magnet, becomes of north polarity. The action of this ringer is usually misunderstood at first sight, the natural supposition being that the limbs of the permanent magnet are of opposite polarity. Besides being a very efficient ringer, this has the advantage of having its working parts inclosed by the rigid permanent magnet, which serves to protect them from mechanical injury.

In Figs. 102, 103, 104, 105, and 106 are shown the details

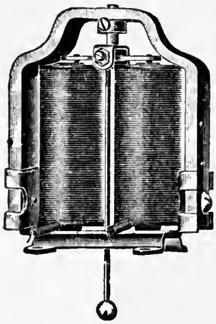


Fig. 101.—Williams-Abbott Ringer.

of a unique magneto-generator and ringer recently put on the market by the Williams Electric Company of Cleveland. This apparatus is the design of Mr. J. A. Williams, and embodies such radical departures from the details of the ordinary magneto as to warrant a somewhat minute description.

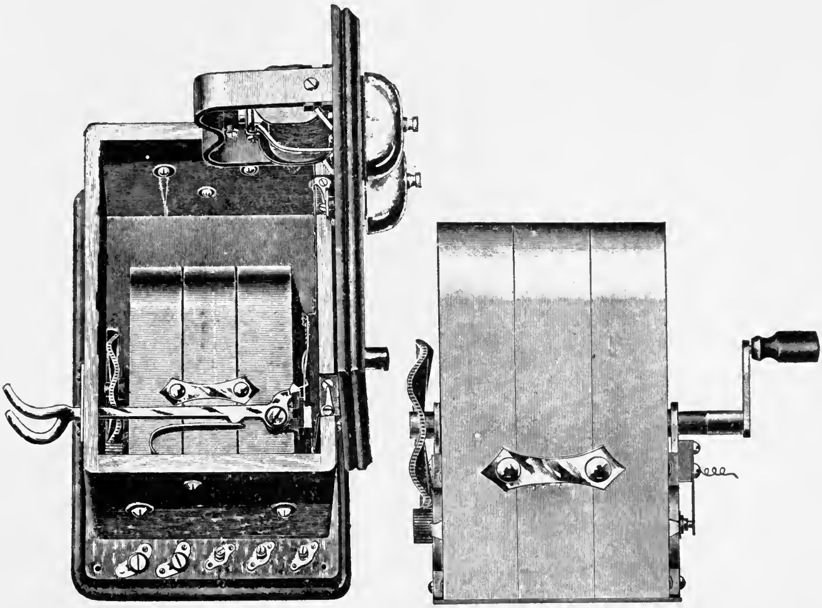
The magnets of the generator are formed of heavy bars of steel, $\frac{3}{8}$ of an inch thick by $1\frac{1}{4}$ inch wide. They are placed close together, thus covering the entire length of the pole-pieces and securing a maximum magnetic density across the pole faces.

The pole-pieces are punched from sheet iron, and are accurately formed to inclose the space in which the armature turns.

The end plates, which hold the crank-shaft and armature bearings, are punched from heavy sheet brass, and have riveted into them long brass bearings, which is an important feature in securing good wearing qualities.

The end plates and the pole-pieces are secured by screws, as shown in Fig. 104, to horizontal brass plates above and below the armature. The method of affording a path for the magnetic lines from the permanent magnets to the pole-pieces is ingenious. Two sheet-iron contact plates are provided, one for each pole-piece. Each of these has two ears turned inwardly to hold it in position on the pole-piece, and also four ears turned outwardly to hold the permanent magnets in their proper place on the generator.

Three portions of each contact plate are left flat or straight, so as to make a good contact surface on the permanent magnets, and two portions are formed so as to make curves coincident



Figs. 102 and 103.—Williams Generator and Magneto-Bell.

with the outside curvature of the pole-pieces. This arrangement is for the purpose of securing good contact between the permanent magnets and pole-pieces, and also for taking the magnetism from the permanent magnets, at points about opposite the center of the armature, thus securing a somewhat longer effective magnet.

The gear and pinion are on the left-hand side of the machine instead of the right, as is usual, the object being to get them as far away as possible from the uneven strain on the shaft due to

the turning of the crank. The feature of the gear, however, is that it is radially corrugated, as shown in Figs. 103 and 104, the object of this being to secure a uniform rate of wear between

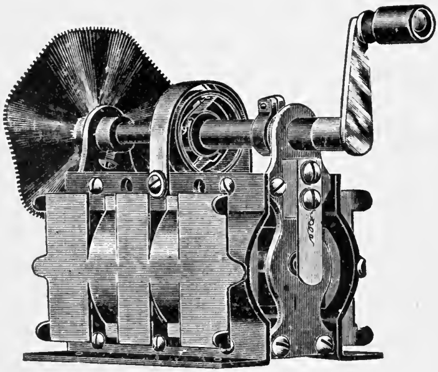
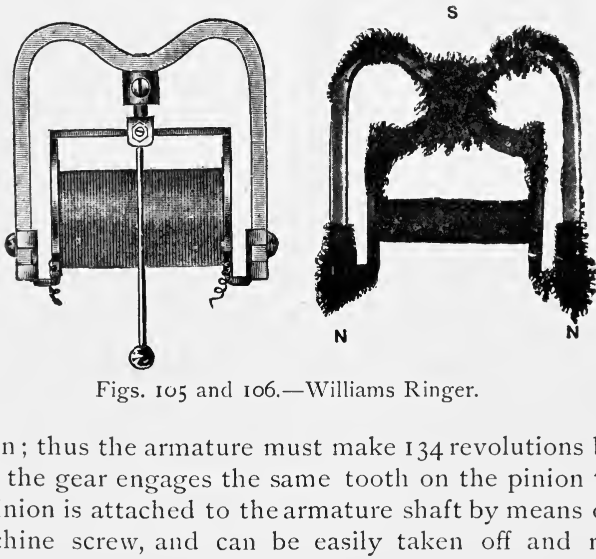


Fig. 104.—Details of Williams Generator.

the teeth on the pinion and on the gear. The corrugations on the gear cause its teeth to play over a width of pinion about five times as wide as the face of the gear. This, in view of the fact that the gear has about five times as great a circumference as the pinion, renders the wearing surface on the two about equal. In order to prevent the large gear plowing a rut in the small one by always traveling in the same path, the ratio of the teeth is made uneven, there being 134 teeth on the large gear and 27 on



Figs. 105 and 106.—Williams Ringer.

the pinion; thus the armature must make 134 revolutions before a tooth on the gear engages the same tooth on the pinion twice.

The pinion is attached to the armature shaft by means of a key and machine screw, and can be easily taken off and replaced

without driving, a feature of great convenience in making repairs.

The magnets are clamped to the frame of the machine by two brass bolts, these being long enough to pass through the bottom of the generator box, so as to receive nuts for securing the generator in the box. The automatic shunt of this machine has already been described in Chapter VIII.

Not less unique than the generator of this machine is the ringer. It has but a single core, which is parallel with the vibrating armature. The core heads or end pieces are formed up of Swedish iron, and are swaged onto the core, forming a very perfect magnetic joint.

The permanent magnet of the ringer is U-shaped and of the consequent-pole type, the central portion being of one polarity and the extremities of the other. The armature is suspended from the central and consequent pole.

The magnetic circuit of this ringer is well shown in Fig. 106 by the iron filings which cling to the poles. It will be noticed that the core of the coil really forms no part of the magnetic circuit of the permanent magnet, as each of its ends is magnetized to an equal extent and with the same polarity.

The action of this ringer is as follows: The two pole-pieces, which form at the same time the heads of the spool, are magnetized by the ends of permanent magnet, with the same polarity—we will say, north. The armature, attached to the center or south pole, will therefore have the opposite polarity—south. When a current traverses the coil, it gives one end of the core and the corresponding head a north polarity and the other end and head a south. This strengthens the magnetism already possessed by the former and weakens that of the latter, thus causing the armature to be attracted by the stronger pole. The next instant the current reverses, and the opposite end of the armature is attracted.

The design of this ringer is certainly good. The length of magnetic circuit through which the magnetism set up by the currents in the coil acts is reduced to a minimum. The ends of the core are subjected to a normal magnetic stress, yet the core forms no part of the normal magnetic circuit. It is therefore rendered very sensitive to changes in the magnetizing force due to the coil, because the normal magnetic flux *through* the core is *nil.*

Fig. 102 shows the complete instrument provided also with a long-lever gravity switch hook, with Craig silver contact-pieces

attached to a hard-rubber block, which, together with the hook, is mounted in the bell box in such a way as to make the switch hook self-contained.

The box is wired throughout with tinned copper wire, which rests between tinned spring washers, secured by entering the binding posts, thus forming spring contacts, all other contacts being soldered.

The regular 10,000-ohm magneto set usually has an armature wound with No. 35 or No. 36 B. & S. silk-covered wire, to resistances varying from 400 to 550 ohms. The ringer magnets are usually wound with No. 31 B. & S. wire and have a resistance of from 75 to 100 ohms. The ordinary construction of ringer magnets is to drive the fiber heads directly onto the cores, and after insulating the surface of the latter to wind the spools thus formed with silk-insulated wire of the desired size. Fig. 107 shows one of

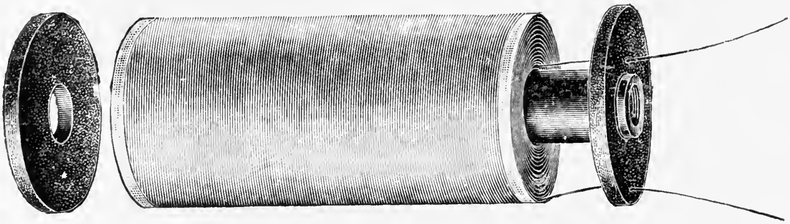


Fig. 107.—Varley Ringer Coil.

the sectional coils of the Varley Duplex Magnet Company. Their coils are wound separately, with bare wire separated by silk thread. After winding, the coils may be slipped on the core and locked by the end washer or head. The advantages of this construction are in the ease of replacing burned-out or otherwise injured coils, and also in the perfect uniformity of the winding. Bare-wire winding will probably play an important part in telephony of the future.

Where many instruments are to be placed *in series* on a party line the ringer magnets should be made as low as 40 ohms, in order to reduce the amount of self-induction through which it is necessary to talk. This is a practice little followed; but good, nevertheless, when instruments must be placed in series.

For bridging work the conditions are changed. The generator must have greater current capacity, and for that reason a larger wire in the winding is necessary. This necessitates fewer turns for the same winding space and a consequent loss in voltage. In some long lines the voltage must necessarily be maintained, and in order to make up for the loss in this respect, due to fewer

turns, the field magnets may be made stronger and the armature longer. A good generator for bridging work may be wound with No. 33 wire to a resistance of 350 ohms.

The ringer magnets for bridging work must possess a very high degree of self-induction. This should be obtained by winding them to a high resistance with a comparatively coarse wire, so as to obtain a large number of turns in the winding. The length of the cores is increased for the double purpose of getting more iron in the magnetic circuit, and therefore a higher retardation, and also for affording a greater amount of room for the winding. The Western Electric Company wind their coils to a resistance of 1000 ohms, using No. 33 single-silk magnet wire. Many other companies use No. 38 wire and wind to a resistance of 1200 or 1600 ohms. This does not give such good results, however, as using the coarser wire and the lower resistance and long cores. Some companies wind, or once wound, their bridging-bell magnets partly with German-silver wire, in order to make a high resistance at a low cost. They should learn, however, that resistance in itself is not the thing desired, but a great number of turns in the winding, which, of course, incidentally produces a high resistance.

CONSTANTLY DRIVEN GENERATORS.

In telephone exchanges, constantly driven generators are employed for ringing purposes, in order that the operators may be

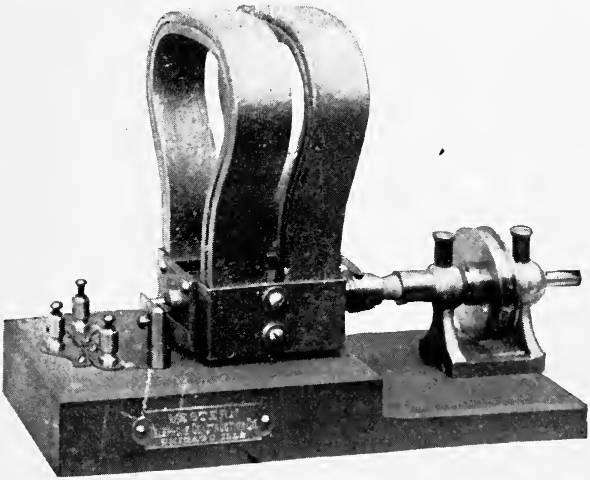


Fig. 108.—Western Power Generator.

saved the labor of manually turning a crank every time a subscriber is called up.

Fig. 108 shows one type of machine for this purpose. It is merely a magneto-generator provided with very long and powerful

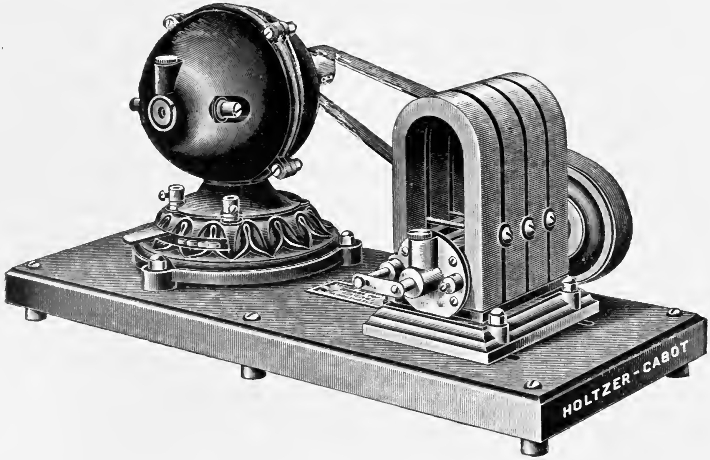


Fig. 109.—Holtzer-Cabot Belt-Driven Magneto.

permanent magnets. The machine is mounted on a slate base and driven by means of a grooved pulley, mounted on a separate

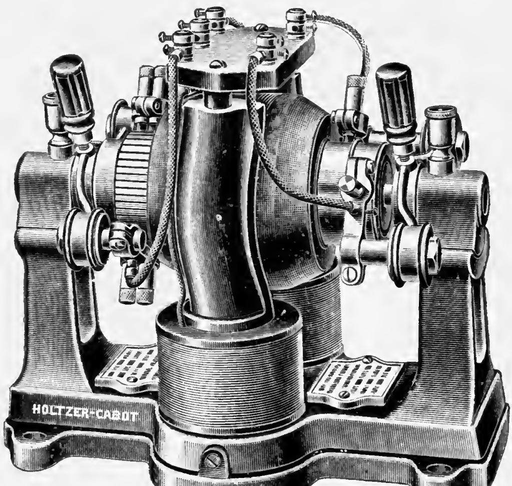


Fig. 110.—Motor-Generator.

shaft connected to the armature shaft by a short flexible rubber coupling.

Machines of this type are suitable for small exchanges, and may be driven by any available source of power. They are

frequently placed in an electric light or power plant, where they may be constantly driven. Wires are then run from them to the exchange, from which the current is sent out over the various subscribers' lines as desired.

Another convenient method of obtaining power for switch-board generators is by the use of small water motors, run from

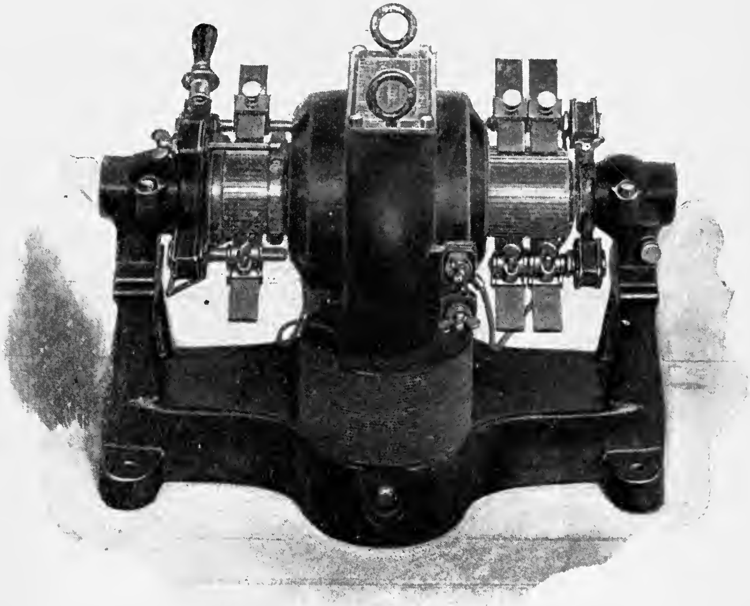


Fig. 111.—Motor-Generator for Battery-Charging.

city water mains. These are specially built for this purpose, and consume but little water.

A more convenient source of power is an electric motor; and Fig. 109 shows a Holtzer-Cabot magneto belted to a small direct-current motor, also manufactured by that concern. Convenient forms of alternating-current motors are also made for running generators for this purpose.

All the machines so far mentioned are suitable for exchanges of 500 subscribers and under. For large exchanges, and also many smaller ones, the motor-generator, types of which are shown in Figs. 110, 111, and 112, are being commonly used. The one shown in Fig. 110 is manufactured by the Holtzer-Cabot Co., and is provided with a double winding, on a single armature core, the same field serving for both windings. The

side having the commutator is the motor side, and may be wound for any desired direct voltage. The right-hand side is provided with collector rings for supplying alternating current for ringing purposes at a pressure of 75 volts.

Fig. 111 shows a machine of similar type manufactured by the Crecker-Wheeler Co. This furnishes alternating ringing current, and besides is provided with an extra winding for supplying low-voltage direct current, for the purpose of charging storage batteries.

In Fig. 112 is shown a similar machine for charging storage batteries in telephone work, and provided with an automatic

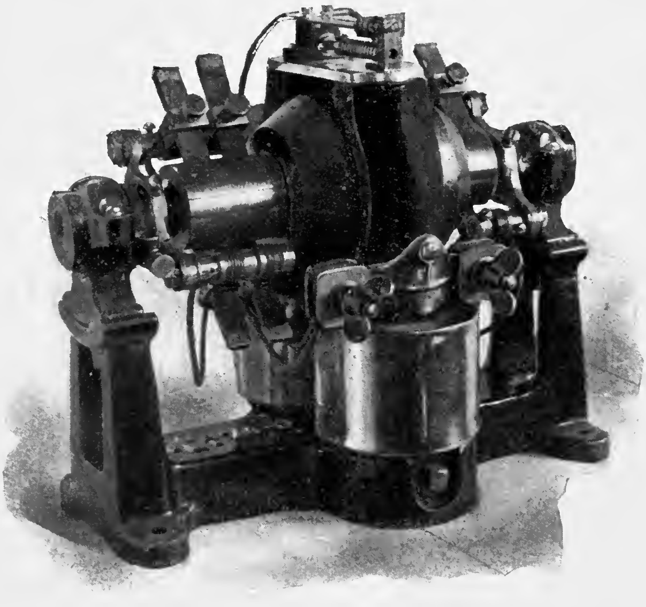


Fig. 112.—Motor-Generator with Automatic Circuit-Breaker.

circuit-breaker on the dynamo side. Considerable trouble has been experienced in storage-battery work, due to leaving the battery in circuit with the generator while the latter was not running. This allows the battery to discharge itself through the armature of the generator, tending to cause the latter to turn as a motor. In order to prevent this, one of the pole-pieces of the machine is hinged at the base, where it joins the bed plate. This pole-piece is normally held away from the armature by a

spring, and in this position the circuit-opening switch, shown on top of the field magnets, is open. When current is supplied to the machine its magnetism causes the pole-piece to draw close to the armature, thus closing the battery circuit. As soon as the machine stops the magnetism weakens, and the circuit is again opened.

CHAPTER XI.

THE TELEPHONE RELAY OR REPEATER.

One of the most attractive fields of research and invention in telephony has been that of the telephone relay or repeater. It has been very natural to suppose that the principle of repeating now used so successfully and extensively on long telegraph lines could be used with equal advantage on long telephone lines. The idea is very simple, and involves merely the placing of a microphone contact in operative relation with the diaphragm of a receiver connected in the first line circuit, and causing the changes produced in the resistance of this contact, when acted upon by the receiver diaphragm, to vary the strength of a current in a local circuit, which circuit would in turn act inductively on the second line wire with reinforced energy.

This method is outlined in Fig. 113, where *A* is the transmitting station, being provided with a transmitter, *T*, battery, *B*, and

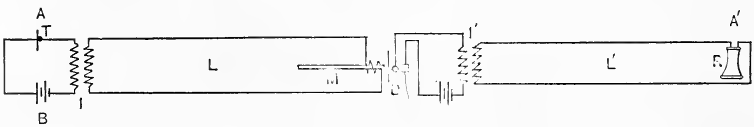


Fig. 113.—Simple Relay Circuit.

induction coil, *I*. *L* is the transmitting line, having connected in its circuit the coil of a receiver, *M*. *D* is the vibrating diaphragm of this receiver against the center of which rests a pair of microphone contacts, which may be the same as those in the Blake transmitter, or of any other type. This microphone contact must be so arranged with respect to the receiver diaphragm that any vibrations of the latter will be imparted to the former, thus causing them to vary their resistance in exactly the same manner as if acted upon directly by sound waves. The microphone contact, *C*, serves to vary the resistance of a local circuit containing a battery, *B′*, and the primary of an induction coil, *I′*. *L′* is the receiving line, containing the secondary of the induction coil, *I′*, at the relay station, and the receiver, *R*, at the receiving station, *A′*. Any changes in current in the local circuit at the station, *A*, produced by the operator at the trans-

mitter, *T*, will induce alternating currents in the line, *L*, in the ordinary manner, which will cause the diaphragm, *D*, to vibrate as in everyday practice. The vibrations of *D* will be imparted to the microphone contact, *C*, which will produce changes in the current flowing in the local circuit at the relay station corresponding to those taking place in the local circuit at station, *A*. These changes will act inductively on the line circuit, *L'*, in the ordinary manner, the receiver, *R*, finally reproducing the sound.

Such an arrangement as this will do its work well, but it is quite evident that the transmission may be effected only in one direction. When it is desired to transmit from station *A'* to *A*, a separate circuit would ordinarily have to be used. Much difficulty was experienced in making a two-way repeater, for no automatic switch could be arranged which would bring about the changes of circuit required when the transmitting station desired to become the receiving. Many attempts were made to associate two relays with the line circuits in such manner that no interference would occur. The difficulties involved in this were, however, great; and chief among them was the fact that two relays when associated with the same pair of lines would almost invariably set up a singing sound, due to the mutual action between the two; for instance, a slight vibration of the diaphragm of one relay would produce changes in current in the local circuit, which would act upon the diaphragm of the other relay, producing another change of current, which would in turn react upon the first relay. This action is somewhat analogous to that produced by holding the earpiece of a telephone receiver directly in front of the mouthpiece of a good granular-carbon transmitter; the singing or shrieking noise set up when a proper adjustment is obtained in this case being due to the fact that the sound waves set up by the receiver diaphragm act upon the transmitter diaphragm, which in turn causes currents to flow through the receiver coil, causing its diaphragm to vibrate still more strongly. This defect, however, was finally overcome, several inventors having produced two-way relays which were successful in so far as they would operate in either direction with equal facility, and with a fair degree of clearness.

One of these systems, devised by Edison, is shown in Fig. 114, in which *A* and *A'* are the telephone stations, each arranged in the ordinary manner. *M* is the magnet of the relay receiver, the coil of which is included in a local circuit containing the secondary, 3, of an induction coil. The primary winding of this coil is divided into two parts, 1 and 2, these parts being connected

together in one side of the combined circuit of the two lines, L and L'. Between the juncture of these two primary coils and the opposite side of the line is connected the secondary coil, 4, of an ordinary induction coil. The primary coil, 5, of this latter induction coil is connected in a local circuit containing the relay microphone contact, C, and the local battery, B''. Assuming that station, A, is for the time being the transmitting station, currents set up in the line circuit, L, will divide at the relay station, part passing through the coils, 1 and 4, and back to the transmitting station, and the other part passing through the primary coils, 1 and 2, in series and to the receiving station

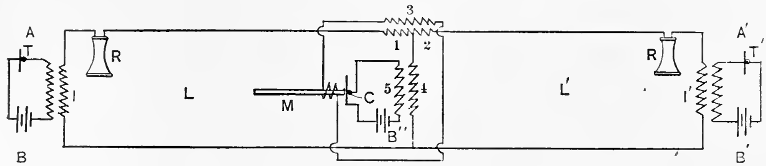


Fig. 114.—Two-way Relay Circuit.

direct. The current passing through the coil, 4, will, however, under ordinary circumstances, be by far the greater on account of the high resistance of the long line, L'. The current passing through the coils, 1 and 2, however, will act inductively upon the coil, 3, thus causing currents to flow through the coil on magnet, M, and produce changes in the contact resistance of the microphone. These changes will cause fluctuations in the current in the local circuit, which fluctuations will act through the primary coil, 5, upon the secondary coil, 4, and cause currents of considerable comparative strength to flow in the line circuit, L', to the receiving station, A'. It is obvious that as the various circuits at the relay station are symmetrically connected with respect to the two lines, L and L', the station, A', may in turn serve as the transmitting station. No reactive effect between the relay transmitter and receiver will in this case be produced, and the means for preventing this forms the most interesting portion of this invention. Whatever currents are set up in the coil, 4, by the action of the microphone contact, C, will divide equally between the primary coils, 1 and 2, passing through them in opposite directions. These coils will therefore act differentially upon the coil, 3, and their effects will be neutralized. No current will be caused to flow in the circuit containing coil, 3, and the relay magnet, M, and therefore no reactive effect will be produced upon the transmitter. In other words, any current

flowing in either line circuit will induce currents in the local circuit containing the magnet, *M*, while currents set up in the coil, 4, by virtue of currents flowing through the magnet, *M*, will produce no effect in turn upon the coil, 3.

A great many improvements have been made in the mechanical construction of the telephone relay, but with few exceptions they have embodied only the idea of combining an ordinary transmitter with an ordinary receiver. In 1897, however, a relay was devised by Mr. A. W. Erdman, and is shown in Fig. 115,

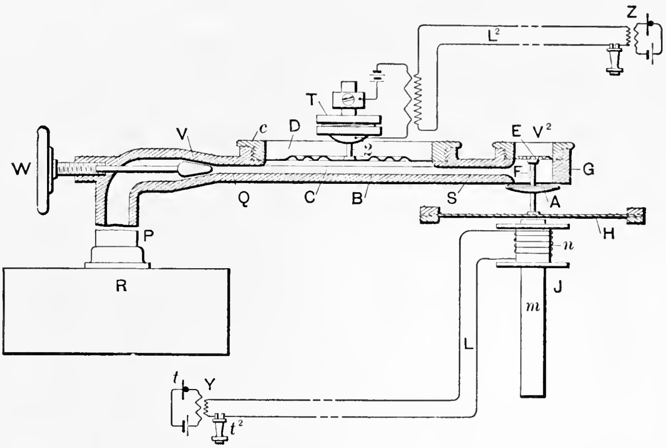


Fig. 115.—Erdman Telephone Relay.

and embodies probably the most radical departure in the structure of telephone repeaters of all since the first was produced. In this figure, *L* is the transmitting line and L^2 the receiving line. *H* is the diaphragm of the receiving instrument and is used to operate the balanced valve, V^2, which by its motion to and fro varies the flow of an otherwise constant stream of air flowing through the chamber, *C*. This chamber is covered by a flexible diaphragm, *D*, which is caused to vibrate by the changes in pressure within the chamber produced by the motion of the valve, V^2. The diaphragm, *D*, serves to operate a microphone, *T*, which in this case consists of the variable resistance button of the solid-back transmitter. *R* is a reservoir containing compressed air, and *V* a reducing valve by which the amount of air escaping through the chamber may be regulated. In the balanced valve, V^2, *E* is a flexible diaphragm and *A* a movable portion which controls the outlet. The centers of the diaphragm, *E*, and of the valve plate, *A*, are connected by the rod, *F*, to the

center of the receiver diaphragm, *H*. The balancing of the valve, V^2, renders it extremely sensitive, so that it may be set in motion by the delicate movements of the diaphragm, *H*. In operation, the vibrations of the diaphragm, *H*, caused by currents in the transmitting line, *L*, cause the balanced valve, V^2, to vary the opening of the air outlet. This produces changes in pressure within the air chamber under the diaphragm, *D*, which cause that diaphragm to vibrate and thus actuate the microphone in the usual way, thus causing currents to flow in the receiving line, L^2, in the usual way. No reports have been made public concerning the results obtained in actual practice with this repeater,

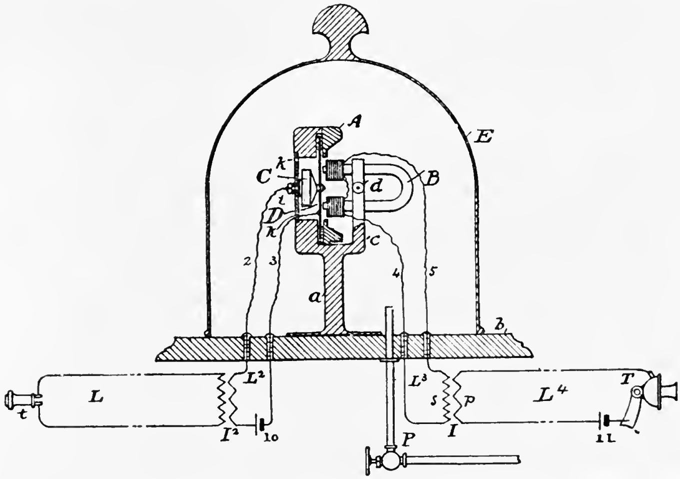


Fig. 116.—Stone Telephone Relay.

but it seems that it may be a step toward the solution of this difficult problem. Instead of employing the mechanical connection commonly used between the diaphragms of the transmitting and receiving mechanisms, Mr. Erdman has, in his current of air or gas, chosen one of the most delicately subtile mediums known.

Another relay, devised by Mr. John S. Stone of the American Bell Telephone Co., is shown in Fig. 116. This relay differs in the essentials of its construction from those of the older type only in that its entire working parts are inclosed in a vacuum chamber. The repeater, together with the circuits of the two connected lines, is shown in this figure, in which *T* is the transmitter of the sending station and *t* the receiver of the receiving station. These are connected with the repeater by lines, L^4 and *L*, respectively, the line circuits being associated with the repeater cir-

cuits by induction coils, *I* and I^2, in the usual manner. *B* is a polarized electromagnet whose poles are in proximity to the diaphragm, *D*. *C* is the variable resistance button of a solid-back transmitter, the front electrode of which is rigidly secured to the center of the diaphragm, *D*, while the back electrode is rigidly secured by means of a cross-piece to the frame, *A*, which also supports the diaphragm, *D*, and the electromagnet, *B*. *E* is a bell jar closely fitted to the base, *b*, by an air-tight joint. The air from within the chamber may be withdrawn by the pipe, *P*, attached to an air pump. It is said that the removal of the air from within the chamber brings about a decided improvement in the operation of the repeater. Concerning the results obtained, Mr. Stone says, "The messages automatically transferred by it from one circuit to another are reproduced in the receiving telephone of the second circuit with a well-defined gain in volume or loudness, and without any substantial distortion or offsetting loss in clearness of articulation." If this claim is borne out in practice, the production of this relay should prove a step of some importance in the matter of long-distance telephony.

It has seemed plausible that very feeble currents received at the relay station would, by virtue of the delicate action of the microphone, be able to produce comparatively large changes in resistance of the local relay circuit associated therewith, and that these changes in resistance would produce correspondingly great changes in the current of the local battery at that station, which changes would act inductively on the second line wire with perhaps as much energy as that imparted to the original circuit. As a matter of fact, however, no gain in the volume of transmission has ever been commercially effected by this method. The telephone repeater may be made to work perfectly on ordinary lines, but it has not shown its ability to transmit speech between two distant points any better than, or quite as well as could be done by direct transmission without the use of the relay at all. The amount of energy received by the electromagnet of the relay is so exceedingly small that it cannot be made to produce the desired mechanical effect upon the microphone contact.

CHAPTER XII.

SELF-INDUCTION AND CAPACITY.

SELF-INDUCTION and capacity play such important parts in the question of long-distance telephone transmission, and seem so little understood among the rank and file of telephone workers and users, that this chapter will be devoted to an elementary and non-mathematical discussion of these two phenomena, with a view to explaining their existence and effect in a simple manner, rather than to throw any new light upon the subject.

Ohm's law states that for a steady flow of electricity in a given circuit the amount of current in amperes is equal to the electromotive force expressed in volts, divided by the resistance of the circuit expressed in ohms. In algebraic form this becomes the well-known equation:

$$I = \frac{E}{R},$$

where I represents the current in amperes, E the electromotive force in volts, and R the resistance of the circuit in ohms. Knowing any two of the above quantities, the third may be determined from the equation already given, or from the following, which are derived from it:

$$E = IR,$$

$$\text{and } R = \frac{E}{I}.$$

These three equations, which are merely different ways of expressing Ohm's law, are the most useful in the entire science of electricity. It is unfortunate for an easy understanding of telephony that these equations in their simple forms hold true for a steady flow only, and that when currents which are rapidly changing in value or in direction are considered, we must face a more complex set of conditions.

An electric current flowing through a conductor sets up a field of force about the conductor throughout its entire length. This field of force consists of magnetic lines extending in closed curves about the conductor, and is often termed a magnetic

whirl. A freely suspended magnetic needle placed within this field of force will tend to assume a direction corresponding to the direction of the lines of force, and therefore at right angles to the conductor.

If the current flowing in the conductor is maintained at a constant value and in the same direction, the field of force about the conductor will not change. On the other hand, if the current strength fluctuates, the field of force will become more intense and will expand while the current strength is increasing, and will become less intense and will therefore contract while the current strength is decreasing. If the current changes its direction, the field of force existing is entirely destroyed, and is built up in an opposite direction at every such change.

Whenever there is such a relative movement between a conductor and the lines of force of a magnetic field as to cause the conductor to cut the lines, or the lines to cut the conductor, an electromotive force is set up in the conductor which tends to cause a current to flow. The direction of the electromotive force will depend on the direction of the lines and on the movement of the conductor, and its value will depend on the rate of cutting. The field of force may be set up either by a magnet or by a conductor carrying a current, and in either case the phenomenon just described is called electromagnetic induction.

If two wires are formed into parallel coils, each having a large number of turns, then the lines of the field of force set up by the coil carrying the current will cut many of the turns of the other wire, thus inducing an electromotive force in each turn; the result being that the sum of all the electromotive forces so induced will be added, thus producing a much greater effect than if each wire consisted of but a single turn. Furthermore, if the two coils are wrapped about an iron core, the field of force due to the coil carrying the current will be greatly strengthened, and therefore the electromotive force induced in the second coil will be greatly increased, owing to the greater rate of cutting of lines caused by the changes in the strength of the current. This is due to the fact that a given magnetizing force, or force which tends to set up a field of force, will produce a greater number of lines in iron than in air.

It is evident that in a coil of wire carrying a current each turn of the coil is surrounded by a field of force, and that each turn must therefore lie more or less within the fields of force of all the other turns. Each turn will therefore have an inductive action upon all the other turns when the current through the coil

is varying. Whenever a diminution of the current occurs the decreasing number of lines of force set up by any one turn will act on each of the other turns to induce an electromotive force tending to cause a current to flow in the same direction. The decreasing field of force around each one of the turns will act in a like manner on all of the other turns, and as all of the electromotive forces in all of the turns will be in the same direction as the current which is already flowing in the coil, their effects will be added and will tend to prolong the flow of current. On the other hand, an increase in the current will cause an increasing number of lines to surround each turn, and this increase around any one turn will induce electromotive forces in each of the other turns in the opposite direction to that producing the current already flowing. This phenomenon of induction between the various parts of a single coil of wire each on the other is termed self-induction.

In view of the fact that a decreasing current induces an electromotive force tending to produce a current in the same direction as that already flowing, while an increasing current induces an electromotive force tending to produce current in the opposite direction, it follows that the general effect of self-induction in a circuit is to tend to prevent any changes in current from taking place in that circuit. This accounts for the fact that coils of wire, such as those forming electromagnets, tend to so greatly reduce the flow of voice currents through them; one of the best illustrations being that used in the bridging bell system of party lines, where the ringer magnets are purposely wound with a great number of turns and provided with long, heavy iron cores for the purpose of increasing the self-induction.

It is quite evident that in circuits containing self-induction and subject to rapidly fluctuating electromotive forces, the tendency of self-induction to prevent changes in the current will always cause any change in current to lag slightly behind the electromotive force which produces it. Where the electromotive force impressed upon a circuit varies according to the law of sines, the electromotive force produced by self-induction lags a quarter of a phase or 90° behind the current flowing in the circuit. That this is so may be seen from the fact that the electromotive force of self-induction is a maximum when the current producing it is changing most rapidly, and is zero when the current producing it is not changing at all. The maximum rate of change of the current flowing in a circuit occurs when the current is passing through zero, and its minimum rate of change occurs at the

crests of the wave, that is, at its maximum points. It therefore follows that the electromotive force of self-induction is a maximum when the current in the circuit is zero, and is zero when the current is a maximum. This evidently indicates a phase difference of 90°, and we have already seen that this phase difference is a lagging rather than a leading one.

In circuits containing only non-inductive resistance the electromotive force impressed upon the circuit has only to overcome the ohmic resistance, and the value of the current may be obtained at any time by a direct application of Ohm's law. Where self-induction, however, is added, the impressed electromotive force, if it be a varying one, must overcome not only the ohmic resistance, but the electromotive force of self-induction; and then the current equation becomes

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Impedance}}$$

The word impedance in this equation may be termed the apparent resistance, and the apparent resistance in circuits having self-induction is always greater than the ohmic resistance. In fact, Z, the impedance, is equal to

$$\sqrt{R^2 + 4\pi^2 f^2 L^2};$$

where f is the frequency of alternations and L is the coefficient of self-induction—a term denoting the total number of lines of force set up in a given coil when traversed by current of unit strength. The equation of the flow of current, I, may then be written

$$I = \frac{E}{\sqrt{R^2 + 4\pi^2 f^2 L^2}},$$

which is the equivalent of saying that the current flowing is equal to the electromotive force divided by the apparent resistance.

The current flowing in a circuit in which self-induction and resistance are present is the resultant of that produced by the impressed electromotive force and the electromotive force of self-induction. The greater the electromotive force of self-induction the greater will be the lag of the current behind the impressed electromotive force. Furthermore, the greater the self-induction the greater will be the apparent resistance or impedance, and consequently the smaller will be the

current flowing. The above formula applies only to currents varying according to the sine law; but telephone currents do not vary according to this law, or according to any other definite law, so far as we have been able to determine. This does not, however, destroy the significance of the formula as applied to telephony. Fourier's theorem states that any complex periodic wave motion may be considered as being made up of a number of simple wave motions having 1, 2, 3, 4, etc., times the rate of vibration of the complex wave motion. Telephone currents are very complex, and are composed not only of a fundamental tone, but of many overtones; it is by the various blending of these overtones, with regard to their relative loudness and their relative position in phase with respect to each other, that articulate speech is produced. A consideration of the formula for the flow of current, just given, shows that the effect of self-induction is greater upon currents of high frequency than upon those of low frequency, for as f, the frequency, increases, the value of the impedance or the apparent resistance increases, and, therefore, the value of the current decreases. In other words, self-induction tends to weed out the higher overtones in preference to the lower ones and the fundamental tone, thus rendering speech indistinct, as well as reducing its volume.

Every insulated conductor is capable of receiving a certain charge when subjected to an electromotive force; for instance, if a metallic plate insulated from all surrounding bodies is connected to one terminal of a battery the other terminal of which is grounded, a certain amount of electricity will flow into the plate until its potential is raised to that of the battery terminal. The plate is then said to be charged, and the amount of electricity held by it determines its capacity. The charge of electricity on the plate will be considered positive or negative, according to whether the positive or negative terminal of the battery, or other charging source, was connected with it.

It is well known that no charge exists by itself—there is always an equal and opposite charge induced by it upon neighboring bodies. It is also well known that like charges repel each other, while unlike charges attract; that if an uncharged body be brought near a charged body an equal and opposite charge will be induced on the side of the uncharged body which is toward the charged body, and that similarly a charge on the same sign as that on the charged body will be induced on the opposite side of the uncharged body. If now the body which was originally uncharged is connected with the ground, this latter charge—that

is, the one of the same sign as the original charge—will be driven to the ground, while the charge of opposite sign will still be attracted by the charge on the first body. The second body will therefore be charged, although it has not been in contact with the first. The action between charges of electricity taking place through an insulating medium is called electrostatic induction. It is found that where two conductors are placed side by side, but insulated from each other, the capacity of each will be greater than if the other were not present. For the purpose of holding charges in this manner the well-known Leyden jars have long been in use. They are usually made by coating a glass jar inside and out with a layer of tin-foil to within a few inches of the top. The outer coating is usually connected with the ground, while the inner coating is connected with a metallic rod approaching it through the mouth of the jar. If the inner coating is connected with a source of electromotive force, a current lasting but an instant will flow into the coating, producing a charge. This charge, which we will say is positive, will attract a nearly equal negative charge to the outer coating, repelling an equal positive charge to the earth, as already described. The amount of charge which the inner coating will receive under these circumstances is very much greater than if the outer coating were not present, and the capacity of the inner coating is therefore much higher than before. A device such as the Leyden jar is called a condenser.

The capacity of a condenser is increased as the area of the conducting surface is increased; is increased as the distance between the conductors is diminished, and may be increased or diminished by using different kinds of insulating material between the conductors. The medium separating the conductors is called the dielectric, and, as stated above, upon it depends to a great extent the efficiency of a condenser. Several condensers built exactly alike, so far as size of plates and the distance between them are concerned, and using different materials for dielectrics, will be found to have different capacities. This difference is due to a peculiar property possessed to different degrees by different dielectrics and called specific inductive capacity.

The specific inductive capacity of a dielectric is a measure of that quality which enables the dielectric to hold a charge between two conductors, as in a condenser. The specific inductive capacity of air is taken as a standard and is for convenience considered as unity; it is lower than that of any other known substance excepting, perhaps, hydrogen. If two condensers having plates of equal size and distance apart are constructed

with dielectrics respectively of air and guttapercha, it will be found that the condenser having the dielectric of guttapercha will receive a charge nearly 2½ times as great as the condenser having the dielectric of air. The actual ratio between the two is 2.462, and for this reason the specific inductive capacity of guttapercha is said to be 2.462. The following table gives the specific inductive capacities of some of the more important insulators:

Air,	1.00
Glass,	3.013
Shellac,	2.74
Sulphur,	2.580
Guttapercha,	2.462
Ebonite,	2.284
India-rubber,	2.220
Paraffin,	1.994
Carbonic Acid,	1.00036
Hydrogen,	0.99967
Vacuum,	0.99941

It is probable that with very rapidly varying electromotive forces, such as are dealt with in telephony, the specific inductive capacities of the various substances would be higher in comparison with air than those indicated by this table.

Specific inductive capacity is a very important consideration in the construction of cables for telephone purposes. In the construction of these cables it is desirable, as will be shown later, to reduce the capacity of the wires of the cable to as great an extent as possible, and in order to do this the dielectric is, in the best forms of cables, made to as great an extent as possible of dry air. On the other hand, in the construction of condensers it is desired that the capacity may be as great as possible for a given area of plates, and therefore some material other than air is used. Paper saturated with paraffin is perhaps the most commonly used, paraffin having about twice as great a specific inductive capacity as air, and moreover lending itself readily to the purposes of insulation. To sum up, the capacity of a condenser varies in direct proportion as the area of its plates, inversely as the square of the distance between the plates, and directly as the specific inductive capacity of the dielectric.

The effect of a condenser bridged across a circuit carrying an alternating current is to absorb a portion of the current as the electromotive force at its terminals increases, and as the electromotive force decreases, to give this current back to the line. Consider such a circuit when the electromotive force active in driving current through it begins to rise. The electromotive force at the condenser terminals will also rise, and current will there-

fore flow into the condenser. The strength of this current will depend directly upon the rate at which the potential at the terminals of the condenser is changing. When the electromotive force acting in the circuit reaches a maximum, the potential at the condenser terminals will also be a maximum and will for an instant cease to change. At this point the condenser is fully charged, but as the electromotive force of the line is not changing no more current flows into the condenser; in other words, the condenser current is zero. As the electromotive force in the line decreases, current will flow out of the condenser and into the line, because the condenser is not capable of holding so much charge at the lower potential. The flow of current out of the condenser reaches a maximum when the electromotive force in the line is changing most rapidly, and this occurs when it is passing through zero. From this it will be seen that the condenser current is zero when the electromotive force in the line is a maximum, and is a maximum when the electromotive force in the line is zero. This indicates, as in the case of self-induction, a phase difference of 90°, or a quarter of a cycle. It is not so easy to say whether this phase difference is lagging or leading, but a consideration of the direction of flow of current throughout the cycle will throw some light upon the subject.

At the instant when the current flowing in the line (which is in exact phase with the active electromotive force in the line *) is positive and at a maximum, the condenser current will be zero. As the active electromotive force decreases toward zero the condenser current increases, but in a different direction,—negative,—because current is now flowing out of the condenser back to the line. As the active electromotive force reaches zero the condenser current is at its maximum negative value, and as the active electromotive force reaches its maximum negative value the condenser current reaches zero. During the next half-cycle the condenser current increases to a positive maximum and decreases to zero, while the active electromotive force passes from a negative maximum to a positive maximum. In other words, while the active electromotive force, and therefore the line current with which it is in phase, decreases from a positive maximum value to a negative maximum value, the condenser current is negative, and while the active electromotive force increases from its negative to its positive maximum value the

* The active electromotive force is the resultant of the impressed electromotive force and the condenser electromotive force, and is in phase with the current actually flowing in the line.

condenser current is positive. The condenser current therefore reaches its zero value, while decreasing, 90° in advance of the same value of the active electromotive force; its maximum negative value 90° in advance of the maximum negative value of the active electromotive force; and upon investigation it will be found that every value of the condenser current occurs 90° in advance of the corresponding value of the actual line current. The electromotive force which is in phase with the condenser current is called the condenser electromotive force, and is 90° in advance of the electromotive force which is active in driving current through the line. This latter electromotive force which, as we have said, is in phase with the current flowing in the line, is the resultant of the impressed electromotive force and the condenser electromotive force, and therefore leads the impressed electromotive force by a certain angular distance.

The current equation for a circuit containing resistance and capacity is, as before,

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Impedance}}.$$

In this case the impedance depends on the ohmic resistance of the circuit and on its capacity, and is equal to the following expression:

$$\sqrt{R + \frac{1}{4\pi^2 f^2 C^2}};$$

where f is the frequency, as before, R the ohmic resistance, and C the capacity of the condenser in farads. From this the current equation becomes

$$I = \frac{E}{\sqrt{R^2 + \frac{1}{4\pi^2 f^2 C^2}}}.$$

The denominator is the apparent resistance, depending upon the ohmic resistance of the circuit, the capacity, and the frequency of alternations. An inspection of this equation will show that as the frequency, f, is increased the impedance or apparent resistance becomes smaller, and this accounts for the fact that a condenser will readily transmit rapidly fluctuating currents, such as voice currents. Evidently the effect of increasing f reduces the second member in the denominator of the equation, and if

sufficiently great, this may be neglected, and the equation becomes simply

$$I = \frac{E}{R}.$$

Again, increasing the capacity of the condenser also increases the effective current by reducing the impedance.

Every telephone line possesses electrostatic capacity, and may be considered in the light of a condenser. In the case of a grounded circuit the line wire takes the part of one plate of the condenser, while the ground and other neighboring conductors act as the other plate. In metallic circuits the one side of the line acts by electrostatic induction upon the other, and the two together upon the ground and neighboring conductors. The capacity of a line, however, differs from that of a condenser in that it is distributed throughout the entire length of a line, while a condenser connected with a line would have all of its capacity at a single point. Capacity such as that of a line is termed distributed capacity in order to distinguish it from that possessed by a condenser, which may be termed local capacity. The effect of distributed capacity upon telephone currents may be more readily grasped by imagining a large number of condensers bridged across the two sides of a metallic circuit at frequent intervals. When the electromotive force impressed upon one end of the line increases, a current flows from the source over the line wire and into the condensers, charging them all according to the difference of potential across their terminals.

The difference of potential across the terminals of all the condensers will not be the same, because there is a certain drop, due to the ohmic resistance of the line wire. If the current flows in that direction long enough to charge all of the condensers on the line then a current will reach the distant end of the line, and if it continues in that direction, will attain its full value, in accordance with Ohm's law. It must be remembered, however, that each condenser is capable of taking a certain charge, and in order to receive this charge a certain quantity of electricity must flow over the line wire.

The quantity of electricity which flows through a circuit depends upon the strength of the current and upon the time it is allowed to flow. If the time is insufficient it will be impossible for enough current to flow through the circuit to charge the condensers up to the potential of the source, and therefore

the current at the distant end of the line will not reach its maximum value, and in fact may not rise practically above zero. If, therefore, the electromotive force of the source is reversed before sufficient current has time to pass through the line to charge all of the condensers, the current will not reach its full value at the distant end of the line.

It may begin to build up in the opposite direction, and again be stopped on account of the insufficient time to reach its proper value in that direction. The time in which the current in such a circuit will reach a definite portion of its maximum value at the distant end of the line is called the time constant, and if the time represented by one alternation of the electromotive force is smaller than the time constant, the current will not reach that value at the distant end of the circuit, and the transmission will be correspondingly impaired.

The reduction in the actual volume of current transmitted by the effects of distributed capacity is, however, of less importance than the distortion of the wave form. The higher frequencies of current waves corresponding to the higher overtones are absorbed by the condensers far more readily than the lower frequencies, and therefore the waves corresponding to the higher overtones are reduced to a much greater extent at the distant end of the line than those corresponding to the fundamental and the lower overtones. This weeds out the upper harmonics, thus tending to destroy the clearness. Capacity, however, acts in still another way to alter the form of the wave. The angle of advance for the higher frequencies is greater than that for the lower, and therefore the waves of different frequencies are shifted with respect to their phase relation, thus greatly altering the wave form.

It has been shown that the electromotive force of self-induction lags 90° behind the active electromotive force, while the electromotive force due to capacity is 90° in advance of the active electromotive force. It is not difficult to conceive, therefore, that by properly proportioning the self-induction and capacity of a circuit the electromotive force of self-induction may be made to neutralize the electromotive force of capacity, and this result is readily obtained in experimental work.

In this case, even though self-induction and capacity may be present in a circuit to a large degree, the current flowing in the circuit is in exact phase with the impressed electromotive force, and its value is in strict accordance with the ordinary expression of Ohm's law. Unfortunately, however, for long-distance teleph-

ony such a balancing of self-induction against capacity can be obtained only for one particular frequency at a time. To thus tune a circuit for one particular frequency would render that circuit capable of transmitting efficiently one particular frequency of vibration, while the requirements of telephony are that all frequencies within the range of the human voice shall be transmitted with equal facility. Again, and unfortunately, it has been found impossible to neutralize distributed capacity with anything but distributed self-induction, and this has not yet been accomplished in practice.

As for trans-oceanic telephony, the high static capacity of the cable has so far proven an insurmountable obstacle. It is impossible to conceive a transmitter capable of forcing such rapid undulations through our present form of cables. Clearly, then, the solution lies in the betterment of cables, or the substitution of some other transmission medium, rather than the improvement of the instruments themselves.

There can be little doubt that trans-oceanic telephony will finally be accomplished, but the indications are that our knowledge at the present time is not sufficient to cope with the problem.

CHAPTER XIII.

TELEPHONE LINES.

In the early days of telephony, the fact discovered by Steinheil, that the earth could be used instead of the return wire of an electric circuit, was made use of, and telephone lines were generally constructed accordingly—that is, with but a single wire, using the earth as the return.

Lines so constructed were, however, soon found to be subject to serious difficulties, chief among which were the strange and unaccountable noises heard in the receiving instruments. There are many causes for such noises, some of which are not entirely understood. The swinging of the wire, in such manner as to cut through the lines of force of the earth's magnetic field, or the sudden shifting of the field itself, causes currents to flow in the line wire which may produce sounds in the receiver. On long grounded lines the variation in the potential of the earth at the ground plates, due to any cause whatever, will cause currents to flow in the line. The passing of clouds or bodies of air charged with electricity will induce charges in the line, and cause currents to flow to or from the earth through the receiving instruments. Electric storms and auroral displays apparently greatly heighten these effects. These noises are of varying character, and Mr. J. J. Carty well describes them in saying:

"Sometimes it sounded as though myriads of birds flew twittering by; again sounds like the rustling of leaves and the croaking of frogs could plainly be heard; at other times the noises resembled the hissing of steam and the boiling of water."

The noises due to these natural phenomena, whatever their true cause may be, are chiefly annoying on long lines, short lines being disturbed only during heavy electrical storms. This is not the case, however, with the noises arising from the proximity of other wires carrying varying currents. Telegraphic signals can be plainly heard in a telephone instrument on a line running parallel with a neighboring telegraph line for a very short distance. The establishment of an electric railway or electric lighting plant in a town using grounded telephone lines will always cause serious noises in the telephones, and if the lighting current is alter-

nating the use of the telephones is usually out of the question at night time, while the plant is running.

Disturbances on telephone lines from neighboring wires may be attributed to one or all of the following three causes: leakage, electromagnetic induction, and electrostatic induction.

Leakage may occur through defective insulation between the two circuits; or even when the insulation of the wires themselves is practically perfect a heavy return current from a grounded circuit, such as of an electric railway, may, upon its arrival at the grounded end of the telephone line, have the choice of two paths, one through the telephone line, and the other a continuation of its path through the ground. This is the greatest source of trouble due to railway work, on grounded telephone lines. A strange fact in connection with this is that the noises in the telephones do not correspond with the fluctuations due to the commutator of the generator armature, as would be supposed, but

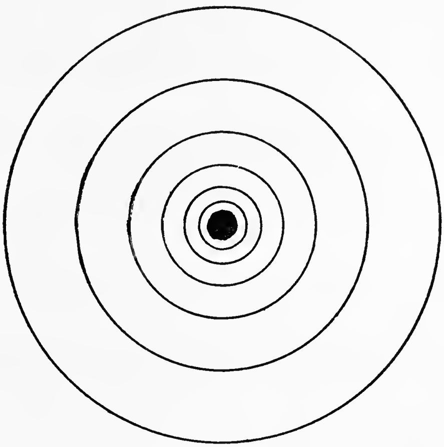


Fig. 117.—Magnetic Lines around a Conductor.

to the movements of the armatures on the car motors. The tone in the receiver is an indication of the movements of the car, and variations in speed may be clearly noticed.

Electromagnetic induction is due to the fact that the telephone line lies in the field of force set up by the disturbing wire. About every wire carrying a current there is a field of force, or "magnetic whirl," consisting of closed lines of force surrounding the conductors. Such a condition is represented in Fig. 117. If the current is a continuous one, the lines of force will not vary after being once set up, and the telephone wire lying in this field will not be

affected. If the current in the disturbing wire is fluctuating, the number of lines of force in this field will vary; or, by a clearer way of expressing it, the field of force will expand and contract accordingly. This expansion and contraction of the field will cause its lines of force to cut the telephone wire, and will by the laws of electromagnetic induction cause currents to flow in the latter. If the current in the disturbing wire is an alternating one, the field of force around it will be established in one direction, destroyed and established in the reverse direction, and again destroyed, with every complete cycle of the current. It is easy to see that this will produce a maximum disturbance in the telephone wire.

Electrostatic induction may be explained by reference to Fig. 118, where a grounded telephone line is shown running parallel with a disturbing wire, which we will say is carrying an alternating electric current. The disturbing wire will receive from its source of current alternate positive and negative charges of electricity, and its potential will pass from a maximum in one

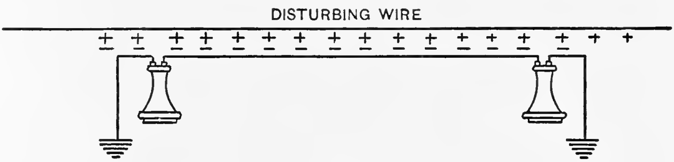


Fig. 118.—Electrostatic Induction.

direction through zero to a maximum in the other, and again through zero to the maximum in the first direction during each cycle.

Consider the condition where the potential of the disturbing wire is zero. No charge will then be induced on the telephone wire, so that its potential will also be zero. The charge on the disturbing wire then becomes, we will say, positive, and this induces a bound negative charge on the side of the telephone wire nearest the disturbing wire, and an equal positive charge on the opposite side. This latter charge is not bound, and flows to earth through the receivers at each end. This flow will be toward the ground, through each receiver, and the current is therefore from the center of the wire in each direction to the ground. The next instant the potential of the disturbing wire becomes zero, thus relieving the bound negative charge on the telephone wire, which flows to earth, or, more properly, is neutralized by a flow of positive electricity from the

earth. Thus each change in potential of the disturbing wire causes a flow of current through the receivers at each end, this flow always being toward or from the middle point in the length of the wire. These currents produce noises in the receivers at each end in the ordinary way.

When two grounded telephone circuits run side by side, each acts inductively on the other, so that a conversation carried on over one circuit may be heard in the telephones on the other. This phenomenon is aptly termed cross-talk, and is usually ex-

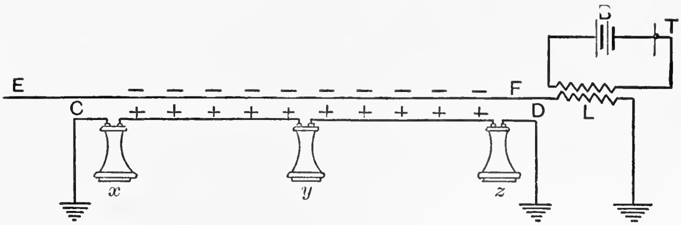


Fig. 119.—Electrostatic Induction.

plained in text-books and articles on the subject by the supposition that it is chiefly if not entirely due to electromagnetic induction.

In 1889, however, Mr. J. J. Carty, in a paper before the New York Electric Club, and again in 1891, in another paper before the American Institute of Electrical Engineers,* described a series of experiments which show conclusively that cross-talk between lines is due almost entirely to electrostatic induction, electromagnetic induction playing so small a part as not to be noticeable.

The arrangement of circuits in one of his experiments is shown in Fig. 119, in which *E F* and *C D* are two well-insulated lines, each 200 ft. long, and placed parallel with each other throughout their entire length, at a distance of $\frac{1}{8}$ in. apart. *E F* is the disturbing line and is left open at *E*. At *F* it is connected through the secondary of an induction coil, *L*, with the ground. In the primary circuit of this coil is a battery, *B*, and a Blake transmitter, *T*. A tuning fork vibrating before the transmitter acted on the diaphragm in the usual way, and caused impulses on the line *E F* of practically the same strength as voice currents. These impulses are, of course, alternately positive and negative, and may be considered in the same light as the impulses on the disturbing line in Fig. 118. Three receivers,

* These papers should be read by all interested in this subject.

x, y, and z, were placed in the line $C\ D$, the receiver, y, being at the middle point in the line. Upon operating the tuning fork, its musical note could be distinctly heard in receivers, x and z, while y remained silent.

In explaining the action of static induction in connection with Fig. 118, it was pointed out that the flow of induced currents would be either toward or from the middle point in the length of the wire. The silence of the receiver, y, in this case bears out that statement, showing the central point to be neutral. If this were electromagnetic induction, the induced current would pass from one end of the line, $C\ D$, to the other, returning through the ground, in which case all the receivers would be affected. As it is, however, the induced charges flow in each direction from the receiver, y, to the ground at each end, or from the ground at each end to the receiver, y, thus in no case causing its diaphragm to vibrate. The same results were obtained by grounding the point E through an ordinary telephone. The receiver wire still remained silent, while x and z were both affected to an equal degree.

It was also found that opening the central point of the line,

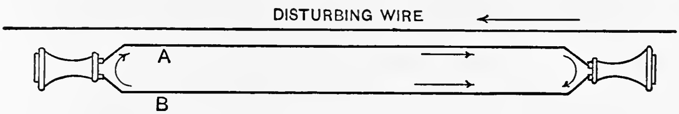


Fig. 120.—Electromagnetic Disturbances.

$C\ D$, produced no effect whatever on the existing conditions; the noises in the receivers, x and z, were plainly heard and of equal loudness.

Many other experiments were tried, the results in each case pointing conclusively to the induction from voice currents being of an electrostatic instead of an electromagnetic nature.

There is no doubt, however, but that induction from wires carrying heavy currents, such as are used in lighting and power work, is largely due to electromagnetic effects, and this can be easily proven by experiments similar in nature to those described.

The one remedy for all the troubles due to disturbing noises from any of the causes is to make the line a complete metallic circuit. Even this will not completely stop noises from most of the causes, and all additional precaution must be taken, by making the two sides of the circuit alike in all respects and properly

transposing them at frequent intervals, in order that they may be as nearly symmetrical with respect to the disturbing source or sources as possible.

Merely making the line a metallic circuit, as in Fig. 120, does not give complete freedom from inductive troubles from other wires, whether the induction be electromagnetic or electrostatic. Considering the question from the standpoint of electromagnetic induction, a current flowing in the disturbing wire would set up a field of force, the lines of which would cut conductors, *A* and *B*. *A* being closer, however, would be cut by more lines than *B*, and consequently any currents induced in *A* by changes in this field will be stronger than those in *B*. If a current starts to flow in the disturbing wire from right to left, as shown, the induced currents in *A* and *B* will each be from left to right, as indicated by the arrows. These currents will partially annul each other, but that in *A*, being the stronger, will predominate, and the resultant will flow in the circuit in a direction indicated by the small curved arrows.

A single transposition in the center of the metallic circuit will completely annul the electromagnetic induction if the disturbing wire is parallel to the two wires throughout its entire length, and if it carries the same current in all its portions. Here an impulse in the direction of the arrow in the disturbing wire (Fig. 121) will

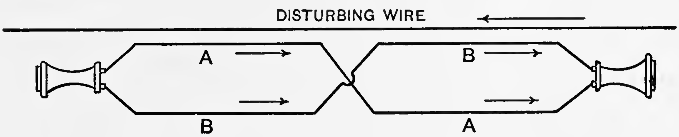


Fig. 121.—Electromagnetic Disturbances.

cause impulses in the opposite direction in both wires, *A* and *B*. As the average distances between the disturbing wire and *A* and *B*, respectively, are the same, the strengths of the induced currents in *A* and *B* will be equal, and they will, therefore, annul each other, producing no sound in the receivers.

It is found, however, that a single transposition in the center of the metallic circuit will not free the line from cross-talk, even though the average distance from the two wires and the disturbing wire is the same, and the current strength is uniform throughout the entire length of the disturbing wire.

Mr. Carty's experiments throw much light on this point. In Fig. 122 is shown a disturbing wire and a metallic telephone circuit composed of two wires, *A* and *B*, of which *A* is nearer the

disturbing wire than *B*. At a time when the charge on the disturbing wire is positive, as shown, a negative charge will be drawn by it toward the disturbing wire and a positive charge will be repelled from it. The result is that the distribution of charges on the two wires, *A* and *B*, will be somewhat as shown, a negative charge being held on the wire, *A*, and a positive charge driven to the wire, *B*.

In order for this rearrangement to have occurred, it is evident that a flow of electricity must have taken place from *A* to *B*, and as two paths were afforded from the center point, *a*, on the wire *A*, of equal resistance, this flow must have been from that point in each direction as indicated by the arrows, through the receivers and toward the center point, *b*, on wire, *B*, where the two currents met. Upon the charge on the disturbing wire becoming zero the potentials on *A* and *B* become equal, by a flow of positive electricity from the center point of wire, *B*, to that of wire, *A*. The negative charge on the disturbing wire, which follows the positive

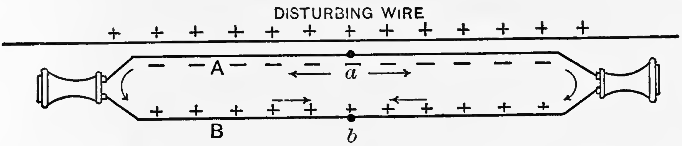


Fig. 122.—Electrostatic Disturbances.

charge, will cause this latter to flow from *b* to *a*, to continue until *A* is positively and *B* negatively charged.

It is evident, therefore, that alternating currents flow through two receivers, and that these currents differ in phase from that in the disturbing wire by 90 degs., which is characteristic of the action of condensers. Further consideration will show that the points *a* and *b* are neutral, and experiment bears out this conclusion, for by opening the wires at those points the sound in the receivers at the ends still continues.

Where receivers are connected in the circuit at *a* and *b* no sound is heard on them, although plainly audible in the end receivers. A single transposition in the center of the line, as shown in Fig. 123, will tend to reduce the sound in the end receivers, but will not cause silence. The static charges on the portions of the wires nearest to the disturbing wire now find four paths instead of two to the more remote portions of the circuit, the flow being clearly indicated by the arrows. The center points, *a* and *b*, are no longer neutral, and receivers placed in the circuit there will be subject to noises.

It is evident that if receivers of equal impedance to those at the ends of the line were placed at *a* and *b*, the neutral points, *c*, *d*, *e*, and *f*, would be found at the quarter points on the line; *i. e.*, midway between the transposition and each end. As a matter of fact, however, no instruments are placed at the point of transposition, and the neutral points are shifted toward the ends of the line, because the impedance of the receivers at those points

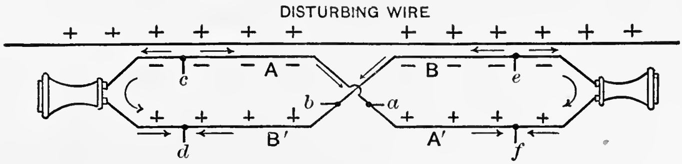


Fig. 123.—Electrostatic Disturbances.

makes it easier for most of the current to pass through the transposition wires.

Theoretically, the currents set up in a metallic circuit by electrostatic induction from another circuit can be eliminated only by making an infinite number of transpositions. Practically, however, it is found that on long circuits transpositions every quarter- or half-mile are amply sufficient to render them unnoticeable.

The scheme of transposition used by the American Telegraph and Telephone Company on the New York-Chicago telephone line is shown in Fig. 124. It will be seen from this figure that trans-

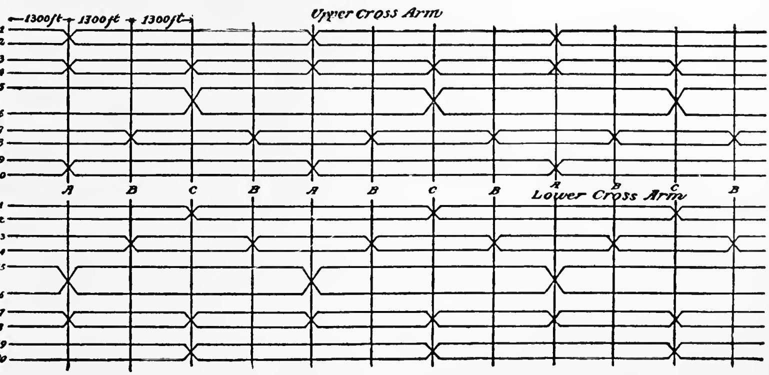


Fig. 124.—Diagram of Transpositions.

positions are made on this line practically four times in every mile, that is, upon every tenth pole; and while this involves the placing of transposition insulators on poles a quarter of a mile

apart, it does not follow that every circuit is transposed at each of these intervals. The reason for this arrangement is that if two lines running side by side were transposed in exactly the same manner throughout their lengths, the desired non-inductive condition would not be secured for the relation between the corresponding wires in the two circuits would then be the same as if no transpositions whatever had been made. In order to overcome this difficulty, transpositions on the second circuit should be made twice as often as those on the first. This is the scheme adopted in Fig. 124, where it will be seen that the center pair of wires on each set of cross-arms is transposed every mile, while the pair immediately adjacent to it on each side is transposed twice as often. The outside pairs on each cross-arm are transposed only once per mile, but these transpositions are staggered with respect to those on the center pair. The same scheme is followed out on every cross-arm, but the transpositions on the top set of cross-arms are staggered with respect to those on the set immediately below—this being the case throughout the entire number of cross arms on a pole; the 1st, 3d, 5th, 7th, and 9th being transposed according to the scheme shown in the upper part of Fig. 124, while the circuits on arms Nos. 2, 4, 6, 8, and 10 are transposed according to the scheme in the lower part of this figure.

A very perfect transposition is effected by twisting two sides of a circuit together, and this idea is followed out in the English pole-line construction, where the two sides of the circuit are not only transposed laterally, but also pass successively over and under each other several times in each mile, thus effectually giving the circuit a number of complete twists. This method, however, involves several disadvantages in the stringing of wires, and increases the liability of crosses between them. It is not, therefore, adopted to any considerable degree in this country.

The twisted pair of insulated wires used so largely in inside wiring, and also in cable work, accomplishes the transposition of circuits very thoroughly, it in fact amounting to a complete transposition for every twist of the wires. This method is now depended upon entirely in the construction of telephone cables, with so great a degree of success as to absolutely prevent all induction between the circuits. This will be discussed at greater length in the chapter on cables.

Where a number of lines radiate from a central point to a number of subscribers' stations the cheapest way of arranging the circuits, if expense alone is to be considered, is to make each

a grounded circuit. This is done by grounding each line at the subscribers' station after it has passed through the telephone there, and also at the central office after it has passed through the coil of the annunciator or signaling device. Such an arrangement is shown in Fig. 125, and it may be assumed that the lines there shown run in the same direction—on the same poles or in the same cable—to the various subscribers whom they serve. In each case *D* is the line drop at the central office and *R* represents the entire telephone set at the several subscribers' stations.

It is evident that, with such an arrangement, disturbances in the receivers may be produced by any one or all of the causes already considered. An electric light or power wire, carrying a

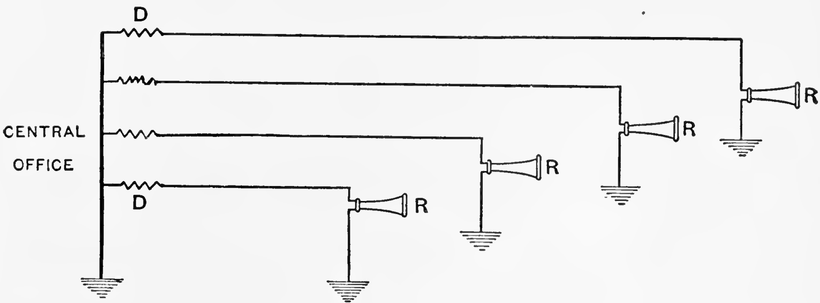


Fig. 125.—Ground-Return Systems.

heavy current, may cause trouble by electrostatic or electromagnetic induction, or by leakage ; and, moreover, each telephone wire, when in use, may be a disturbing wire to all of the others.

As has been pointed out, the proper remedy for these disturbances is to make each line a separate metallic circuit, and to properly transpose the two sides of each circuit at frequent intervals where the lines are long. This course is followed in most large telephone exchanges, and many small ones; but it frequently happens that commercial considerations will not allow it in smaller installations. Where this is the case a system called the common-return or McCluer system is frequently used, with excellent results. The layout is the same as that of the grounded system, with the exception that the return of every circuit is made through a heavy wire common to all of the circuits. A clear conception of the common-return system may be had by considering a heavy wire, Fig. 126, to take the place of the earth in a grounded system ; each line wire being connected to it at or near the subscriber's station after passing through the telephone

instrument, *R*, and at the exchange after passing through the switch-board drop, *D*.

It is quite evident that the common-return system will, if properly installed, remove all trouble due to leakage or earth currents; for the entire system of wiring may be kept highly insulated from the ground and from other conductors. Practice, however, differs to a large extent in this respect, as some companies ground the common-return wire at the exchange, and also at several other points along its length, others at the exchange only, while others keep it entirely insulated from earth. Probably the reason for placing several grounds on the return wire is to effect a reduction in the resistance of the return path, but this, if needed, should be brought about in another way. Probably the best practice in most cases is to keep entirely free from grounds, although there are many who claim to have effected a marked improvement by heavily grounding the common return at the central office. At any rate, this is an easy experiment to try. The location of the common-return wire with respect to the

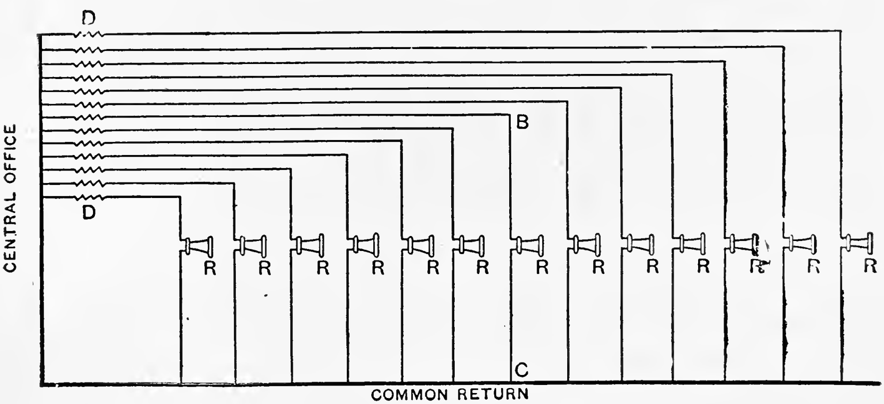


Fig. 126.—Common-Return Systems.

other wires on the poles is a question concerning which there is much difference of opinion. Undoubtedly the best way of disposing it, so far as purely electrical considerations are concerned, is to place it on brackets between the two middle cross-arms on the poles, for then it bears a more symmetrical position with respect to all of the line wires and is, therefore, better adapted to neutralize induction from outside sources. It is, however, often put on other parts of the pole, sometimes above all the wires, sometimes on a bracket just below the top cross-arm, and frequently below the lowest cross-arm. The latter is prob-

ably the most convenient place, as wires led off to buildings will usually stand clear of the other wires on the pole.

There is even more difference of opinion as to the proper size of the common-return wire than as to its location. An analysis of the inductive action from neighboring wires may perhaps throw some light upon the subject. If we assume that the entire system is insulated from the ground and from other conductors, it will be safe to say that all disturbances in the telephones due to leakage or earth currents will be eliminated. The only way, therefore, by which neighboring wires can affect the telephone wires is by induction, and this may be either electromagnetic or electrostatic, or both. The ideal arrangement of the common-return wire with respect to the line wires would be that in which all were at an equal distance from the disturbing wire. This condition can only be roughly approximated in practice, but in Fig. 127 it will be assumed that the disturbing wire, which may be a

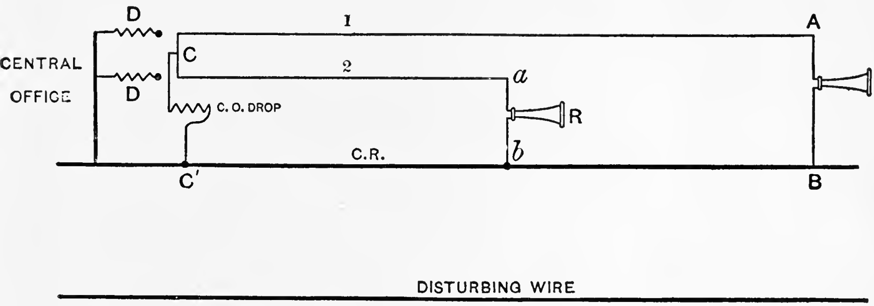


Fig. 127.—Induction on Common-Return Lines.

trolley or electric light line, is at approximately the same distance from the line wires, 1 and 2, from the return wire, *C R*. The lines, 1 and 2, are connected at central by the cord circuit, *C*, a clearing-out drop being bridged between the cord and the common return, and the line drops, *D D*, cut out as in ordinary practice.

It is evident that if no sounds are to be produced in the receiver of Line 1, the points, *A* and *B*, must be of equal potential. Similarly the points, *a* and *b*, must be of equal potential for no disturbance to be produced in the receiver of Line 2, and the points, *C* and C^1, for no current to flow through the clearing-out drop. It matters not if *C*, *a*, and *A* are all of different potentials, the one requisite for silence in the receivers being that the

two points at the terminals of each shall be of the same potential The question, therefore, becomes, what size of wire shall be used for the common return in order to bring about these conditions?

Considering the induction from the disturbing wire to be electromagnetic, it is evident that the electromotive force set up in the several wires will be proportional only to their lengths, as their distances from the disturbing wire is assumed to be the same in each case. The sizes of the wire will have nothing to do with the pressure developed, any more than the size of the wire *per se* affects the electromotive force developed in the armature winding of a dynamo. In the case of the wire, 1, the E. M. F. generated in the length, $C\ A$, will equal that generated in the length, $C^1\ B$, of the common-return wire. This means that the points, A and B, have the same potential as have also C and C^1, and no current will flow through the receiver of that line or the clearing-out drop. By the same reasoning the pressure developed in length, $C\ a$, of Line 2 will equal that in the length, $C^1\ b$, of the common return, and no current will flow through the receiver of Line 2. So far as electromagnetic induction is concerned, therefore, the size of the common-return wire is immaterial.

Considering the question from the standpoint of electrostatic induction, it will be seen that for a given charge on the disturbing wire charges of the same potential will be induced on each of the line wires and on the common-return wire. There will, perhaps, be a tendency for the small wires to assume charges of slightly higher potential than the larger wire, on account of their smaller radius of curvature, but this would be so slight as to be negligible under the conditions assumed, and would be eliminated were the common-return wire made of the same size as the line wires.

So far as inductive disturbances from outside sources are concerned, it seems that the size of the common-return wire is practically immaterial, with perhaps a slight theoretical advantage to be gained by making it of the same size as the line wires. This view seems to be at direct variance with nearly all written statements on the subject.

The same reasoning will show that when any one of the telephone lines is considered as the disturbing wire, the same conclusions are reached.

So far no valid reason has been shown for making the common-return larger than the line wires. There is, however, a good reason why this should be done, and this is the fact that

the return circuit of any one wire is made, not only through the common-return wire, but also through all of the other line wires in multiple. Referring to Fig. 126, it is evident that currents generated in line, *B C*, may find a return path through the common-return wire, and through all of the other wires in multiple. In fact, all of these return paths will be chosen, the current dividing among the other line wires and common return, inversely as to their respective impedances.

The currents flowing through these other lines would produce cross-talk were they of sufficient magnitude to do so, and the only way of preventing this is to make the common-return wire of such low resistance that practically all of the current will pass through it. The fact that the common-return wire may be made to possess practically no self-induction, and, therefore, only the impedance due to its ohmic resistance; while the line wires all include in their circuits either the receiver and induction coils or the bell and drop coils, serves to divert nearly all of the current through the common-return wire, where it belongs. On account of the marvelous sensitiveness of even poor receivers, a comparatively small resistance in the common return will shunt enough current through the various instruments to cause cross-talk to a considerable extent.

There is undoubtedly a large amount of copper wasted in common-return wires, and it is probable that a No. 8 B. & S. gauge copper wire will in most cases answer the purpose. It too frequently happens that larger common-return wires are used in the hope of remedying a difficulty which is due to another cause entirely. Cross-talk in switch-boards and office cables is often attributed to the smallness of the return wire, which in this case might be increased indefinitely without improving the service.

Of course, the ideal conditions assumed for the disposition of the wires cannot be attained, and in so far as they are not attained, induction is likely to occur.

It frequently becomes desirable to connect a grounded line with a metallic line, and for this purpose what is known as the repeating coil forms the most ready solution. A repeating coil is merely a special form of induction coil, usually constructed in the form shown in Fig. 128. The primary and secondary coils are wound upon a heavy core formed of a bundle of soft-iron wires, after which the ends of the cores are bent around the outside of the coil, thus completely inclosing it in a casing of wire. The coil is then clamped to the base, usually by metal straps, as

shown in the figure. The terminals of the primary are brought out to binding posts at one end of the base, while those of the secondary are similarly brought out to binding posts at the opposite end. The wire forming the core should be of No. 24

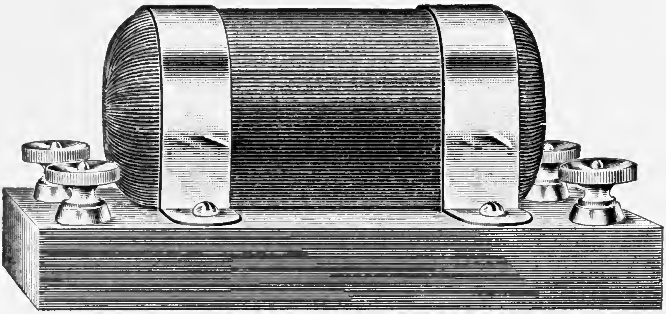


Fig. 128.—Repeating Coil.

annealed iron formed into a bundle about $\frac{3}{4}$ of an inch in diameter. The two coils are usually made equal in resistance and in number of turns, 200 ohms for each coil being perhaps the most common figure. No. 31 B. & S. gauge silk-covered wire is a suitable size for a coil adapted to ordinary work. Of course these figures may be departed from to almost any degree in order to design coils for special work.

In Fig. 129 is shown in diagram a metallic circuit line connected with a grounded line through a repeating coil. The two

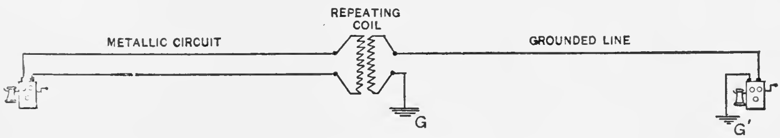


Fig. 129.—Connection of Metallic and Grounded.

terminals of the metallic circuit line are merely brought to the two binding posts of one of the coils, while the terminal of the grounded line is brought to one of the binding posts of the other coil; the remaining binding post is then grounded. Any varying currents set up in one of the circuits will act inductively on the other circuit through the windings of the coil, each of which may thus be called upon to act alternately as a primary and a

secondary. By the use of the repeating coil in this manner, two lines may be connected for conversation without grounding one side of the metallic circuit, which would be necessary were the repeating coil not used.

There is a very common impression among the independent telephone users that a repeating coil is the one panacea for all of the evils connected with grounded lines. It is perhaps well to correct this impression, by saying that no number of repeating coils will render a noisy grounded line quiet. A repeating coil will, however, prevent the unbalancing of a metallic circuit line, and therefore in many cases insure a degree of quietness on two connected lines which would otherwise be unattainable.

It sometimes happens that a long grounded line is paralleled throughout a portion of its length only by some disturbing wire,

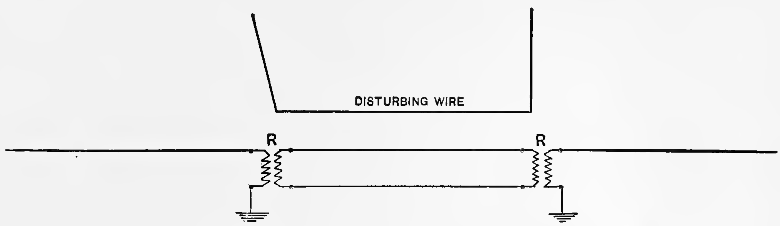


Fig. 130.—Eliminating Local Induction.

such, for instance, as an electric-light line. Where it is not possible from commercial considerations to make the entire line a metallic circuit, much relief may sometimes be had by resorting to the plan shown in Fig. 130, which consists in making only that portion of the line a metallic circuit which is within the direct influence of the disturbing wire. The two ends of the grounded line may then be connected with the intermediate metallic portion by means of the repeating coils, *R R*, as shown. By this arrangement the disturbing wire produces no effect on the metallic circuit between the repeating coils, if proper precautions are taken in the way of transposing its two sides. Telephonic communciation may be had over the entire length of line, the currents undergoing two transformations at the repeating coils.

Much trouble is often had where it is necessary to ring through repeating coils, especially if the lines are very long. It is therefore advisable that repeating coils should always be placed at a central station if possible, and such arrangements

made that it will not be necessary to ring through them. However, a coil properly constructed with a magnetic circuit completely closed should serve as a very efficient transmitter, even for the slowly alternating currents of a magneto-generator, and good results may be obtained with such coils on good lines even when it becomes necessary to ring through them.

CHAPTER XIV.

SIMPLE SWITCH-BOARDS FOR SMALL EXCHANGES.

THE object of a telephone exchange is to afford means for placing any telephone user (subscriber) into communication with any other subscriber in the same system. The lines leading to the telephone instruments of the various subscribers radiate from a central point where they terminate in an apparatus known as a switch-board.

Switch-boards may be divided into two classes, manual and automatic. In the manual switch-board, operators—girls—are employed to make the connections called for, while in the automatic, the operation of connecting or disconnecting lines is performed by the subscriber desiring the connection. The manual switch-board only will be considered at present, as it is in almost universal use, the automatic, owing to its great and necessary complexity, having proven successful only in rare cases.

The simplest form of switch-board, one typical of the kind used in small exchanges and designed for use on grounded or common-return systems, will first be considered.

Each line entering the exchange terminates in what is known as a spring-jack. Spring-jacks are sockets containing or associated with simple switching devices and are mounted on the face of the board within easy reach of the operator. In order to make a connection with any line, plugs are provided which may be inserted into the jacks, and thus continue the electrical path from the line wire terminating therein, to and through a flexible conducting cord attached to the plug.

Fig. 131 shows a simple spring-jack with a connecting plug inserted. The metallic base, *a*, of the jack, usually of brass, is drilled from its forward end to receive the shank of the plug, *P*. A forwardly projecting sleeve on this base fits snugly into a hole bored in the front board, *A*, of the switch-board, to which it is fastened by the shoulder and small wood-screw as shown. Firmly secured to the rear end of the piece, *a*, is the line spring, *c*, formed with a rearwardly projecting tongue, to which the wire, *l*, leading from the line is soldered. The forward end of the spring, *c*, rests normally against the pin, *p*, carried by, but in-

sulated from, the base, *a*. A wire, *g*, leads from this pin, and through the coil of the line annunciator or drop to ground. When the plug is inserted in the jack its conducting tip makes contact with the tip of the line spring and at the same time forces it out of engagement with the pin, *p*. Normally, therefore,

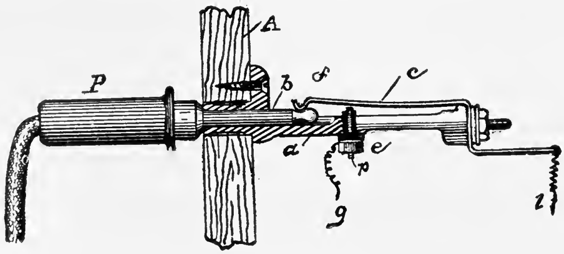


Fig. 131.—Spring-Jack.

the line wire is connected to the ground through the wire, *l*, spring, *c*, pin, *p*, wire, *g*, and line-drop to the ground connection. When the plug is inserted in the jack, however, the line is disconnected from the branch leading through the drop, but is connected through the medium of the plug to the flexible cord.

Fig. 132 shows a common form of switch-board drop. The purpose of the drop is to attract the attention of the operator whenever any subscriber wishes a connection. The coil of the electromagnet is mounted on the back of the front plate, *c*, of the switch-board, as shown. To the armature, *a*, pivoted at its upper end, is attached a rod, *b*, passing forward through a hole in the front plate and provided with a hook on its forward end, adapted to engage the upper portion of a pivoted drop-shutter, *s*, and to hold it in its raised position. The attraction of the armature due to a current passing through the coil causes the hook to rise, thus releasing the shutter, which falls to a horizontal position and displays to the operator the number by which that line is designated.

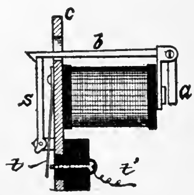


Fig. 132.—Switch-Board Drop.

In order to attract the attention of the operator at night or at such times as she may not be in sight of the board, a night-alarm attachment is provided on each drop, which serves to close the circuit through a battery and vibrating bell whenever the shutter is down. The small cam surface on the lower portion of the shutter, *s*, forces the light spring, *t*, into contact with the

pin, t', when the shutter is down, thus accomplishing the above result.

Fig. 133 shows diagrammatically the circuits of such a switch-board. But two subscribers' lines with their spring-jacks and

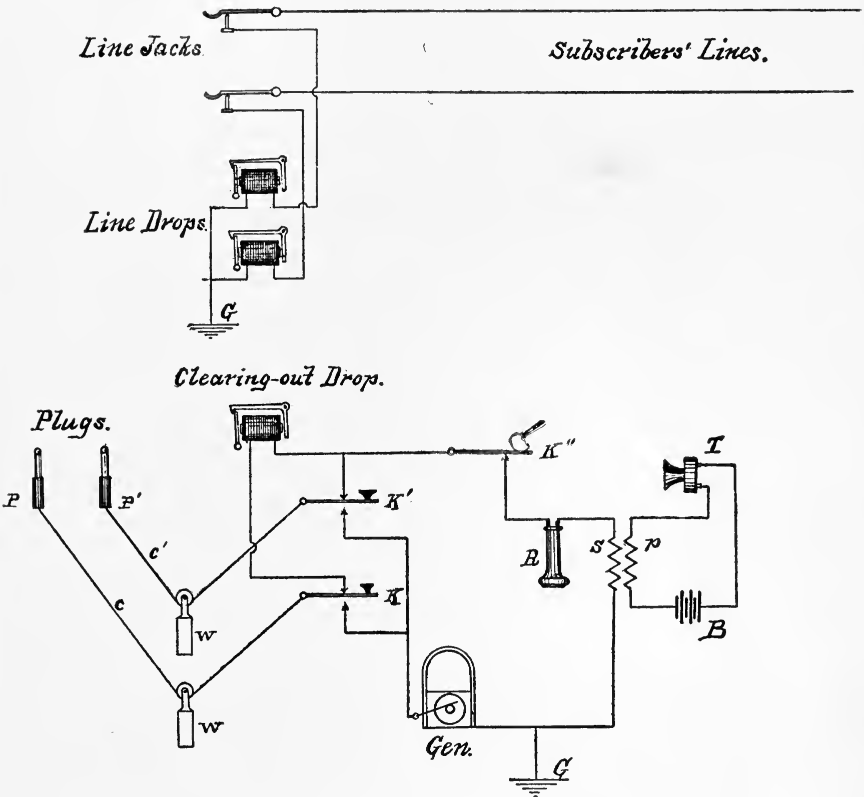


Fig. 133.—Switch-Board for Grounded Lines.

drops are shown. These, it will be noted, enter by the line spring of the jack, and thence when the plug is not inserted their circuits pass through the contact pin of the jack through the electromagnets of their respective drops and to ground at *G*. In the lower portion of the figure, *R* represents the operator's receiver, *T* her transmitter, *B* the transmitter battery, *s* and *p* respectively the secondary and primary windings of the operator's induction coil, *P* and *P'* a pair of plugs, and *K*, *K'*, and *K''* keys connected therewith, the purpose of which will be described later. When one of the line drops falls, indicating that the subscriber on that line desires a connection, the operator takes

up the plug, P', and inserts it into the jack bearing the corresponding number, say, No. 20. She then moves the lever of the key, K'', into the position shown—that is, so that the spring of this key makes contact with the stop below. This movement connects the operator's telephone set with the telephone of the subscriber calling, the circuit being traced from ground at the subscriber's station through his instrument to his line wire, from the line wire to the line spring in the jack, thence to the plug, P', cord, c', to the lever of the key, K', through the upper contact of this lever to the lever of key, K'', thence through the operator's receiver and the secondary of her induction coil to ground, G.

She now ascertains from the subscriber the number of the line with which he desires connection, which we will say is No. 63. She thereupon takes up the other plug, P, of the pair and inserts it into jack 63. In order to call subscriber No. 63, she presses the key, K, into contact with its lower stop. This completes connection from the ground at the central office, through the operator's generator, through key, K, cord, c, plug, P, jack No. 63 to subscriber No. 63, and through the ringer magnet of his instrument to ground. All keys being in their raised position, the two subscribers may converse with each other over the following path: line wire No. 20 to jack No. 20, plug, P', cord, c', key, K', through the upper contact of this key, through the coil of the clearing-out drop to key, K, thence through cord, c, plug, P, jack 63 to subscriber 63. In case at any time the operator wishes to "listen in" to ascertain if the parties are through talking, she may do so by depressing key, K'', which throws her telephone into a branch or derived circuit of the circuit between the two subscribers. The key, K', may be used to connect the generator with the line to which the plug, P', is connected.

The clearing-out drop is placed in the circuit between the two plugs to indicate to the operator when either of the subscribers turns his generator to ring off.

But a single pair of plugs with their corresponding keys and clearing-out drop are shown, for simplicity's sake. It is usual to place ten of such pairs of plugs for each one hundred subscribers in the system, it being found that this number is sufficient to meet the requirements at the busiest periods of the day.

The drops in a board of this type are usually wound to a resistance of about 80 ohms, unless designed for multiple or bridged telephone lines, in which case the resistance of the drops is the

same as that of the ringer coils of the telephone instruments on that line, usually 1000 ohms.

This switch-board has not been described because it is a fair example of modern, up-to-date apparatus, but because, stripped of all complicated devices for facilitating the work of the operator, it can be more easily comprehended by the beginner. A large number of such switch-boards are, however, in use, and for small exchanges may give as good service as it is possible to obtain with grounded or common-return lines.

It has already been pointed out that in order to avoid induction and other sources of trouble, metallic circuits are rapidly superseding ground circuits in telephone exchanges. The switch-boards in common use for small metallic-circuit exchanges are built on the same general principles as those for grounded circuits just described, differing from them only in such details as to render possible the connections of the two branches of one line with those of another line through the cord circuits. For this purpose two separate contacts are provided in each jack forming the terminals of the two branches of the line. The plugs also have two separate contact-pieces adapted to register with the contact-pieces in the jack when a connection is made. Each contact on the plug is connected to a similar contact on the other plug of a pair through the medium of a double-conductor flexible cord.

One form of metallic-circuit jack is shown in Fig. 134. Here the tubular portion, *a b*, forms a terminal for one side of the line,

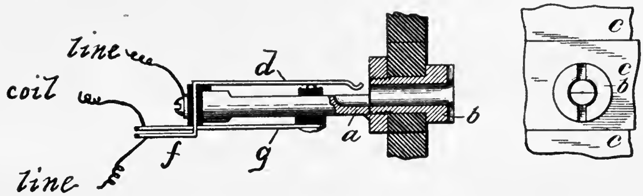


Fig. 134.—Metallic-Circuit Jack.

while the flexible spring, *d*, forms the terminal for the other side of the line. The terminal, *g*, connected with the pin upon which the spring, *d*, normally rests, forms one terminal for the coil of the line-drop. The other terminal of this coil is attached to the terminal, *a*, so that when the spring, *d*, is in contact with its pin the circuit is complete from one side of the line to the other through the drop coil. The tubular frame of this jack is made in two pieces, *a* and *b*. The front portion, *b*, is a hollow screw,

threaded to engage a tapped hole in the front of the piece, *a*. By this arrangement any jack may be readily removed from the board by unscrewing the piece, *b*, until it disengages the rear portion, *a*. A slot for receiving a screw-driver is provided on the front of the piece, *b*, to accomplish this.

A metallic-circuit plug in common use is shown in Fig. 135. The tip conductor is formed of a rod of brass slightly enlarged at

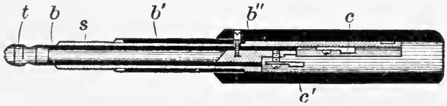


Fig. 135.—Metallic-Circuit Plug.

its forward end. This is encased in a bushing, *b*, of hard rubber, and over this is slid a tube, *s*, of brass forming the sleeve of the plug. A second bushing, *b'*, covers the rear portion of the sleeve, *s*, and the rear portion of this latter tube is in turn covered by the tube, *b''*, of hard rubber, forming the handle of the plug. The tube, *s*, forming the sleeve has a portion which projects rearwardly into the handle and is there provided with a connector, *c*, to which the terminal of one conductor of the flexible cord is attached. The other connector, *c'*, is attached to the rear portion of the tip piece, *t*, and forms the terminal for the other conductor of the cord.

In Fig. 136 is shown a form of jack and plug manufactured by the American Electric Telephone Co. The jack is self-

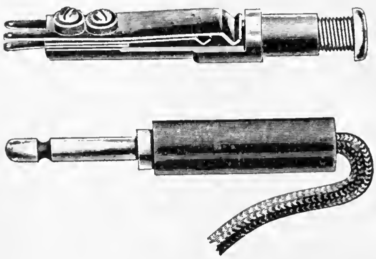


Fig. 136.—American Jack and Plug.

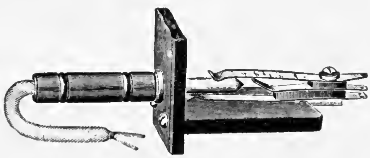


Fig. 137.—Keystone Telephone Co.'s Jack and Plug.

contained and is mounted on the board by means of a screw-threaded thimble, in much the same manner as the jack shown in Fig. 134. The two springs are secured rigidly to the frame of the jack, but are insulated from it and from each other by strips of hard rubber and by insulating bushings for the screws. The plug differs in its details from that shown in Fig. 135, but its

contacts perform the same functions. The entire metal portion of the plug, including the tip and sleeve contacts, are screw-threaded into the hard-rubber bushing, forming the handle, and make contact with the terminals of the flexible cord in such manner as to bind it firmly in place without the use of other connectors. The screw-threaded thimble of the jack is provided with a long shank so as to adapt it to fit almost any thickness of panel board. This jack and plug are made with special reference to use upon boards already installed, when it is desired to increase their capacity.

In Fig. 137 is shown another form of jack and plug, manufactured by the Keystone Telephone Co. of Pittsburg, Pa. The construction and operation of this are evident from the cut.

In Fig. 138 is shown in diagrammatic form the circuits of a switch-board of this class. Here the line wires, l^1 and l^2, forming

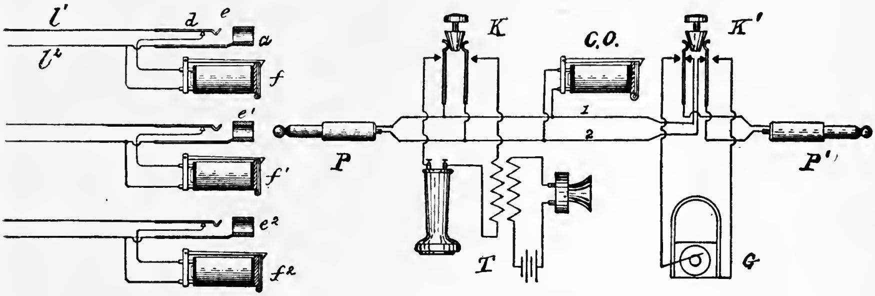


Fig. 138.—Circuits of Metallic Switch-Board.

the two sides of a metallic circuit, enter the spring-jacks, e, e^1, and e^2, in the manner described in connection with Fig. 133. It will be noticed that while the tip-spring, d, is in its normal position, circuit is traced from the line, l^1, through the coil of the drop, f, and back to line, l^2, so that current sent from the subscriber's station will actuate the drop, thus indicating a call. When one of the plugs, P or P', is inserted into the jack spring, d is raised from its normal resting-place and breaks contact with the terminal leading to the drop-coil, thus cutting the drop out of the circuit. At the same time, the connection is continued from the two line wires, l^1 and l^2, to the two strands of the cord circuit. When an operator notices that a drop has fallen she inserts the answering plug, P, into the jack corresponding to that drop and by pressing the button, K, belonging to that cord circuit, bridges her telephone set, T, across the two strands, 1 and 2, of the cord circuit. This enables her to communicate with the subscriber call-

ing, to ascertain his wants. She then inserts the calling plug, P', into the jack of the called subscriber and presses the button, K', thus connecting the terminal of the generator, G, with the two sides of the line of the subscriber called.

It will be noticed that when the key, K', is in its normal position the conductors from the tip and sleeve of the answering plug to the tip and sleeve of the calling plug are made continuous by the springs of the calling key resting against their inside anvils. When the key is depressed the springs break contact with the inside anvils, thus severing the connection between plugs, P and P', and immediately afterward connect with the outside anvils forming the terminals of the generator, G, thus sending current over the called subscriber's line.

The clearing-out drop, $C\ O$, is permanently bridged across the cord circuit as shown, in order to indicate to the operator when either subscriber rings off. In order that the efficiency in talking may not be impaired, this drop is made of high resistance and high impedance.

The line-drops are usually of the ordinary type described in connection with the grounded-circuit switch-board. The clearing-out drops, however, must be made to meet more difficult requirements than the line-drops. As they are always bridged across the circuit of two connected subscribers, it is found that unless special precautions are taken much trouble will be experienced from cross-talk due to induction between two adjacent drops. This difficulty cannot be overcome, as in the line-drops, by cutting them out of the circuit whenever two subscribers are connected, inasmuch as the very purpose for which they exist requires them to be always in such circuits. Neither can it be overcome by placing the drops at such a distance from one another that this induction will not be felt, for the limited space on switch-boards requires that they be put as close together as mechanical conditions will allow.

It has thus been found necessary to design drops which would neither affect nor be affected by any similar drop in its immediate vicinity. This has been accomplished in several ways, but the best example is that shown in Fig. 139, which illustrates what is known as the "Warner Drop." In this the coil is wound in the ordinary manner on a soft-iron core and is then encased in a tubular shield, *c*, also of soft iron. The armature, *d*, is pivoted at points, *e*, in a bracket, *f*, mounted directly on the rear portion of the tubular magnet. From this armature a rod, *a*, extends forward through a notch in the front plate, *b*, in such manner as

to engage the upper portion of the shutter and thus hold it in its raised position. A screw, *l*, passing through the front plate, *b*, serves not only to hold the magnet in place, but to hold the core in its place within the shell. The terminals of the coil are led out through two small holes in the armature and are connected with the terminals, *h* *i*, mounted on an insulating strip, carried on the bracket, *f*.

These drops should be so nicely made that the armature, *d*, will fit closely against the end of the tube, *c*, in such manner as

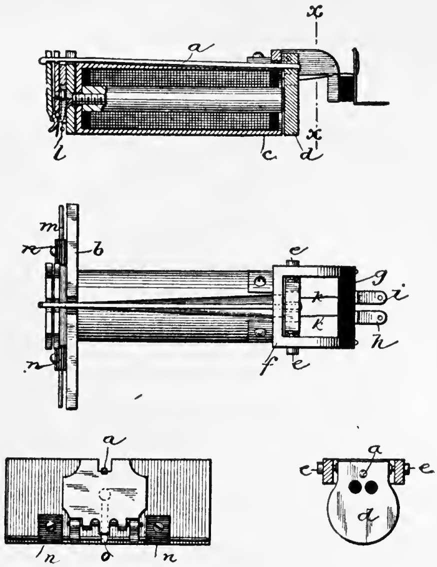
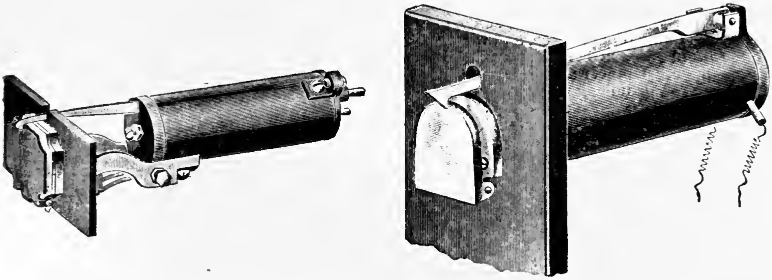


Fig. 139.—The Warner Drop.

to almost completely close the magnetic circuit in which the coil is placed. The lines of force generated by the passage of a current through the coil follow almost entirely the path provided for them by the shell and the core of the magnet, thus not only producing a very efficient electromagnet, but also preventing any of the lines of force from extending beyond the limits of the shell. These drops are usually wound to a resistance of 500 ohms and may be mounted as closely together as desired without producing perceptible cross-talk. The impedance due to the great number of turns in the coil, and to the perfect magnetic circuit surrounding the same, is so great that practically no diminution in the strength of speech transmission is felt due to its being bridged across the two sides of the line.

Another form of tubular drop is shown in Fig. 140. This is manufactured by the American Electric Telephone Co., and needs but slight description. The tubular magnet is mounted on a brass bracket extending from the rear plate of the switch-board, upon the front of which is pivoted the shutter. The armature is pivoted at its lower edge in the brass bracket, and carries on its upper side a forwardly projecting rod which serves as a catch for the shutter. This drop gives excellent service in



Figs. 140 and 141.—American and Keystone Tubular Drops.

practice, but is probably not quite so sensitive as the Warner drop, because the armature in its backward movement must necessarily pull the shutter back slightly before it can release it. This is but a slight objection, however, and does not, as stated above, seriously impair its efficiency.

In Fig. 141 is shown the tubular drop of the Keystone Telephone Company, the arrangement of the parts being evident from the cut.

CHAPTER XV.

LISTENING AND RINGING APPARATUS FOR SWITCH-BOARDS.

In order to accomplish the changes of circuit by which the operator is enabled to connect her telephone with the line of any subscriber, and to send calling current to actuate the bells at any subscriber's station, many forms of circuit-changing switches have been devised. One of these, shown in Fig. 142 and known

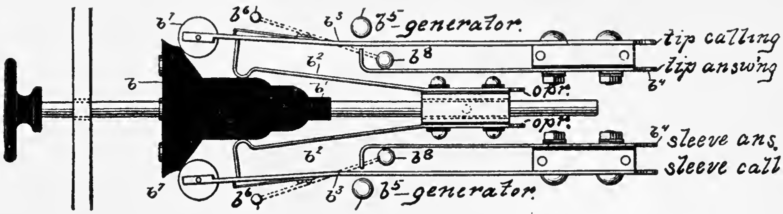
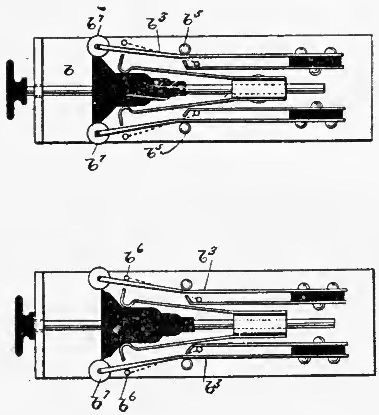


Fig. 142.—O'Connell Key.

as the O'Connell key, has been in use in this country, either in the form shown or with slight modifications, for many years. Six different contact-springs are so mounted and formed as to be acted upon by a wedge, *b*, of insulating material adapted to slide vertically among them. This wedge is mounted upon a rod, carrying at its upper end a button, by which it may be raised or lowered by the operator. The two springs, b^3, form the terminals of the two strands of the flexible cord leading respectively to the tip and sleeve of the calling plug. These springs are provided with rollers, b^7, in order to reduce friction when acted upon by the wedge, *b*. The springs, b^4, form respectively the terminals for the strands of the cord leading to the tip and sleeve of the answering plug. The two springs, b^2, are connected each to one terminal of the operator's set, while the pins, b^5, are connected each to one terminal of the calling generator. The normal position of this apparatus is when the wedge is raised to its highest position. In this position the springs, b^2, rest against the smallest portion, b^1, of the wedge, *b*, and are not in engagement with the springs, b^3. The springs, b^3, however, rest against the springs, b^4, thus making complete the connection from the tip and sleeve of the answering plug to the tip and sleeve, respectively, of the call-

ing plug. In this position two subscribers may converse without being heard by the operator.

When the button is depressed one notch the springs, b^2, ride upon the second portion of the wedge, b, thus forcing them into engagement with the springs, b^3, without causing these latter to break contact with the springs, b^4. In this position the circuit between the two plugs is not broken, but the operator's telephone set is connected across the two strands of the cord, thus allowing the operator to listen in and to communicate with either of the two subscribers who are talking. In its third position, which is that shown in Fig. 143, the springs, b^3, break contact



Figs. 143 and 144.—O'Connell Key.

with both springs, b^2 and b^4, and come into contact with the pins, b^5, which are connected with the terminals of the generator. This sends calling current to the called subscriber without affecting in any manner the circuits leading to the calling subscriber. When the button is depressed to its utmost extent the springs, b^3, are pressed outwardly as is shown in Fig. 144, until they not only make contact with pins, b^5, but also with pins, b^6. These pins, b^6, are each connected to pins, b^8, against which the springs, b^4, are now resting. This completes a circuit from the generator terminal, b^5, through the springs, b^3, to the pins, b^6, thence to the pins, b^8, and thence through the springs, b^4, to the sleeve and tip of the answering plug and to the line of the calling subscriber. Thus, in this final position of the key, calling current is sent not only to the subscriber to be called, but also to the one who originated the call. Of course, this is necessary only when for some reason the calling subscriber has left his instrument.

In later and better keys, arrangement is made whereby either the calling or the called subscriber may be called without disturbing the other.

The combined listening and ringing key shown in Fig. 145 is the invention of Mr. Frank B. Cook, of the Sterling Electric

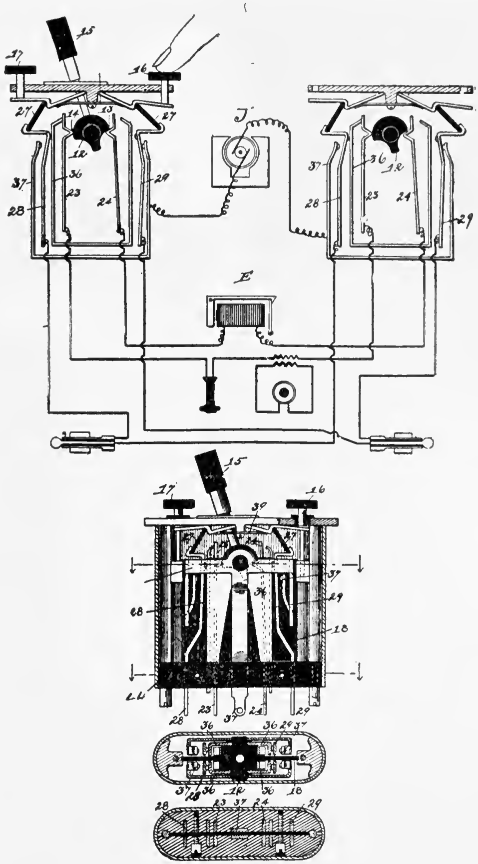


Fig. 145.—Cook Key.

Co. This key is quite extensively used by some of the licensees of the Bell Company, and also in all of the switch-boards manufactured by the Sterling Company. The springs in this key are arranged in duplicate sets, the two sets being divided by a hard rubber partition, 18, as shown in the sectional view at the bottom of the figure. The two sets of springs are shown separated in the upper portion of the figure, and their various circuit connections clearly indicated. The springs are acted upon by the cam, 12, of hard rubber pivoted in the metal frame, and adapted

to be turned through a small arc by the handle, 15. The springs 23, on each side of the partition bear against the left-hand portion of the cam, and form the terminals of the operator's talking circuit including her receiver and the secondary of her induction coil. On the opposite side of the cam are the two springs, 24,

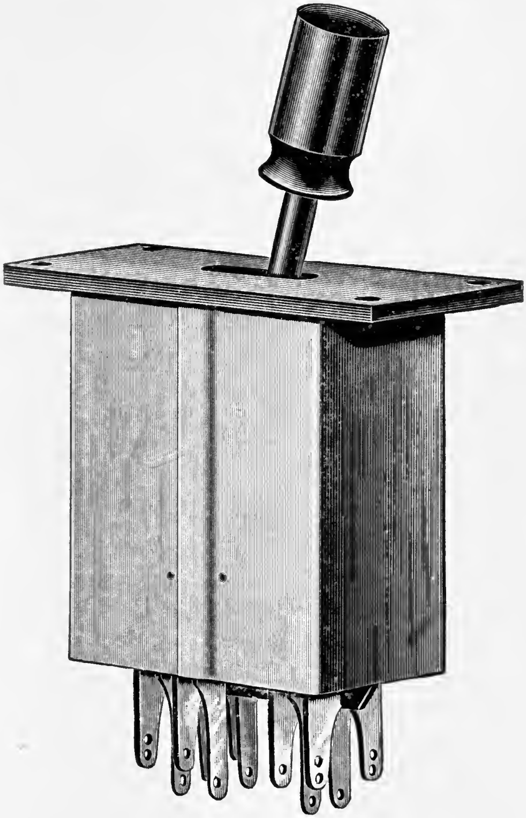


Fig. 146.—American Key.

forming the terminals of the clearing-out drop, *E*, one of them being placed on each side of the partition. The springs, 28, form the terminals of the tip and sleeve strands of the calling plug, while the springs, 29, form the terminals of the two corresponding strands of the answering plug. These springs normally rest against the two contact strips, 36, so that the tip of the calling plug is normally connected through one of the strips, 36, to the tip of the answering plug, and similarly the sleeve of the calling plug with the sleeve of the answering plug through the other strip, 36. When the cam is rotated in one direction the listening

springs, 23, are pressed into engagement with the two strips, 36, thus bridging the operator's telephone across the two sides of the cord circuit. When the cam is in its opposite position the two clearing-out springs, 24, are pressed into engagement with these strips, thus bridging the clearing-out drop across the cord circuit. This latter position is the normal position of the cam. Two outside terminal strips, 37, are provided, one on each side of the partition, these forming the terminals of the switchboard generator, *J*. By means of pressure on one of the buttons, 16 or 17, the contact springs, 29 or 28, may be pressed out of engagement with the strips, 36, and into engagement with the generator terminals, 37, thus disconnecting the strands of the cord from the rest of the circuit and at the same time connecting them with the generator terminals. Upon releasing the button the springs resume their normal position, completing the circuit between the two plugs and cutting out the generator. These circuit changers have the advantage of being entirely self-contained, thus rendering the removal of any one of them from the switch-board a comparatively easy matter when repairs are necessary. They are entirely inclosed, and are therefore quite free from dust, which causes much trouble in the way of poor connections in many otherwise efficient circuit changers.

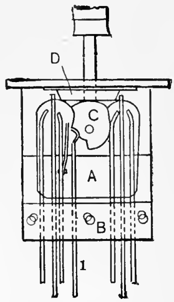


Fig. 147.—Sectional View American Key.

A new key, just put upon the market by the American Electric Telephone Co., is shown complete in Fig. 146 and in section in Fig. 147. In this all of the listening and ringing operations are performed by the manipulating of a single lever, no buttons being required to perform the ringing, as is usually the case. As in the Cook key, two sets of springs are provided, being separated by a partition, *A*, of hard rubber. The springs are mounted in slits cut in hard-rubber blocks, *B*, these blocks being clamped between two brass side-plates forming the frame of the circuit changer. The front one of these side-plates is removed in Fig. 147 in order to better show the construction.

The circuits of this apparatus are shown in Fig. 148, the two sets of springs being separated in order to render their action clearer. It should be remembered, however, that the cam, *C*, acts in the same manner on each set of springs, so that the two sets always occupy similar positions. The pair of springs, 1, form the terminals of the operator's set, and are adapted to make contact with the springs, 2, when the lever is pressed to the right. The

springs, 2, normally bear against the springs, 4, which form the terminals of the tip and sleeve strands respectively of the answering plug, *P*. The springs, 3, make normal contact with the springs, 5, which form the terminals of the tip and sleeve strands of the calling plug, *P'*. As the springs, 2 and 3, on each side are permanently connected together, it follows that in the normal position of the circuit changer the tip strand is made complete through spring, 4, spring, 2, spring, 3, and spring, 5, and the sleeve strand

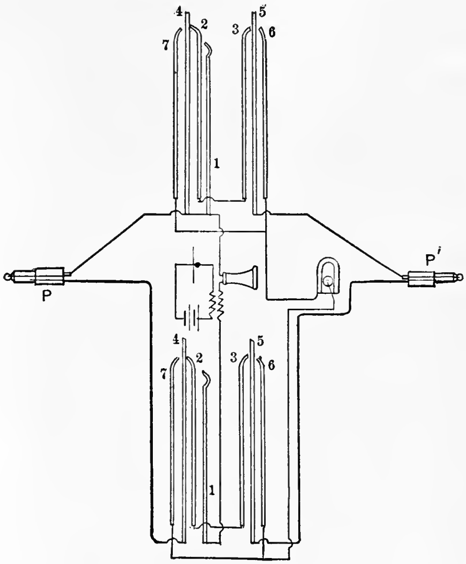


Fig. 148.—Circuits American Key.

is made complete through the same springs on the other side of the partition. When the cam lever is thrown to the right, the springs, 1, are, as before stated, pressed into engagement with the springs, 2, thus bridging the operator's telephone across the combined cord circuit. When the lever is pressed still further to the right, the rubber plate, *D*, carried upon it, presses the springs, 5, into engagement with the springs, 6, at the same time breaking the contact with the springs, 3. As the springs, 6, form the terminals of the switch-board generator, this sends calling current over the line with which the calling plug, *P'*, is connected. No current is sent to the line with which the other plug is connected, because the circuit is broken between springs, 3 and 5, on each side of the partition. In a similar manner a pressure of the lever to the extreme left causes the springs, 4, to break engage-

ment with the springs, 2, and to come in contact with the springs, 7, which also form terminals of the calling generator. This sends calling current over the line with which the plug, *P*, is connected.

The combined listening and ringing key of the Western Telephone Construction Co. is operated entirely by one lever, this lever being normally held in its central position by the contact springs against which it operates. In order to connect the operator's telephone across the terminals of the cord circuit with this key, the lever is pushed straight down without rocking it at

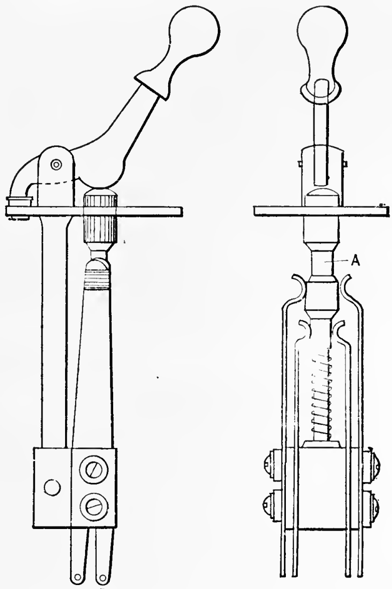


Fig. 149.—American Listening Key.

all, this action pressing the light operator's springs into contact with the tip- and sleeve-springs of the cord circuit. When the lever is rocked toward the operator, the tip- and sleeve-springs of the calling plug are pressed into engagement with the generator contacts, thus at the same time cutting off the connection with the tip-spring of the answering cord. A rocking motion in the other direction presses the tip- and sleeve-springs of the answering plug into engagement with the generator contacts, at the same time cutting off the tip-springs of the calling cord.

Fig. 149 shows a simple key manufactured by the American Electric Telephone Co., and typical of a large number of keys designed for the purpose of either listening or ringing. In this the plunger, *A*, is of hard rubber, and is normally pressed into

its upper position by the spiral spring below it. It may be depressed, however, by means of the lever, in an obvious manner. The outside springs form the terminals of the cord circuit, while the inside shorter springs may form the terminals of the operator's telephone set or of the calling generator, according as to whether the key is to be used for listening, or for ringing purposes. When the plunger is depressed, the outside springs fall into the depression on the plunger, while the shorter springs ride upon its enlarged portion, thus pressing the two pairs of springs into contact and bridging the telephone or generator across the cord circuit.

To facilitate the manipulation of switch-boards it is, of course, desirable to make the number of motions necessary to effect a connection as few as possible. If, therefore, some act which must necessarily be performed by the operator in inserting a plug in or withdrawing it from a jack can be made use of to bring about some of the other changes of circuit, a decided advantage is gained. In Fig. 150 a device for accomplishing

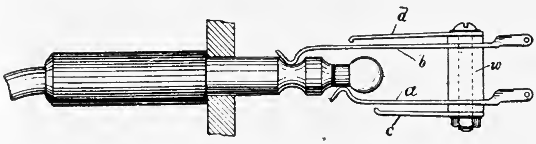


Fig. 150.—Plug Listening Device.

this is shown. The line springs of a jack are represented by *a* and *b*; *c* and *d* are two springs arranged adjacent to the line springs and forming terminals of the operator's telephone set. The plugs are formed with alternate depressions and enlargements, which are so spaced that when the plug is partially inserted into a jack the two line springs ride upon the two enlargements, thus pressing the line springs into engagement with the operator's terminals, *c d*. This places the operator into communicative relation with subscriber. After the operator has learned the connections desired, she inserts the plug fully into the jack, thus allowing the two line springs to fall into the recesses of the plug. This maintains the connection between the line and the conductors of the plug, but breaks the connection between the operator's telephone and the line. The apparatus is then in the position shown in Fig. 150. If at any time the operator wishes to listen in without breaking the connection between two subscribers, she may do so by partially withdrawing the plug. If she finds that they

are through talking, the movement is continued and the plug replaced in its seat. Where this device is used an ordinary ringing key is required to connect the generator across the terminals of the calling plug.

In Figs. 151 and 152 is shown a device in common use, designed by Mr. W. O. Meissner, which accomplishes the con-

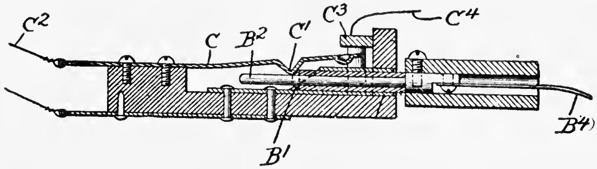


Fig. 151.—Meissner Ringing Device.

nection of the calling generator with the line of the subscriber called for by inserting the plug to its utmost extent into the jack.

The illustrations show a jack and plug for common-return or grounded lines. In Fig. 151 the plug is shown partially inserted into the jack, in which position the line spring, *C*, makes contact at the point, C^1, with the conductor, B^2, of the plug, thus completing the connection between the line, C^2, and the strand, B^4, of the cord. In this position the circuit is continuous between two connected subscribers or between the operator and one subscriber, as the case may be. When it is desired to ring out on the line, C^2, the plug is pressed to its fullest extent into the jack,

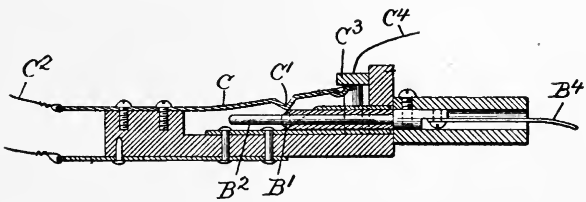


Fig. 152.—Meissner Ringing Device.

as shown in Fig. 152. In this position the spring, *C*, rides upon the insulated sleeve, B^1, of the plug, thus breaking connection between the spring and the contact, B^2, and at the same time pressing the tip of the spring into contact with the strip, C^3, which is connected by wire, C^4, to one terminal of the generator. Current from the generator thus flows to line until the plug is released, at which time it is forced outward by the action of the spring and again resumes the position shown in Fig. 151. Where this device is used, listening in by the operator is accomplished by an ordinary listening key.

In Fig. 153 is shown another device for listening in. *P* is the calling plug of any pair, and is shown in its normal socket on the

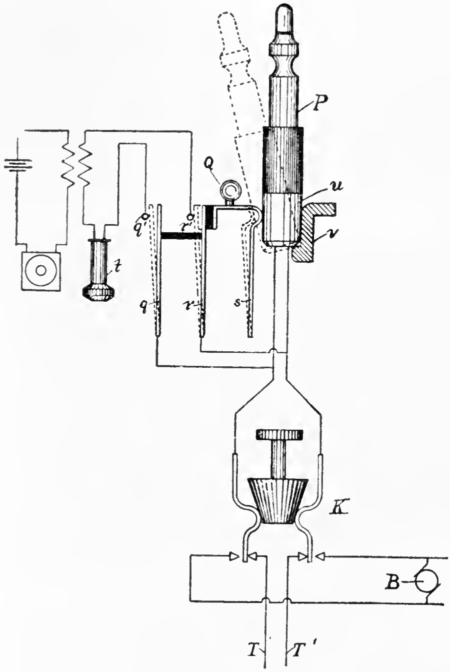


Fig. 153.—Plug Socket Listening Key.

key table. By tilting it in its socket until it assumes the position shown in the dotted lines, the spring, *S*, is forced from its normal position, and thus presses the springs, *q* and *r*, into engagement with terminals, q^1 and r^1. As is shown by the diagram, this act connects the operator's telephone set across the two strands of the cord circuit, TT^1.

The knob, *Q*, upon the spring, *S*, may be used to connect the operator's telephone across the cord circuit, in case it is desirable to listen in after the plug, *P*, has been removed from its socket. Calling is done by pressing the key, *K*. This affords a very rapid means for connecting the operator's telephone into circuit with any line, for after having inserted an answering plug into the jack of a calling subscriber, she can, by part of the movement which withdraws the calling plug, *P*, from its socket, connect her telephone with the calling subscriber's line. A continuation of this movement completes the connection with the called subscriber, and at the same time cuts the operator's telephone out of circuit.

CHAPTER XVI.

SELF-RESTORING SWITCH-BOARD DROPS.

IT is generally considered of great advantage to have switch-boards so arranged that it will be unnecessary for the operator to manually restore the drops. The reason for this is that every movement on the part of the operator, in establishing a connection between two subscribers, requires a certain amount of time, and that in the busier portions of the day an operator is worked almost to the extremity of her endurance, and therefore that the saving of any movements in handling these connections will be a great gain in the rapidity with which the board can be operated. Such saving of the work of the operator not only insures a quicker and therefore a better service,

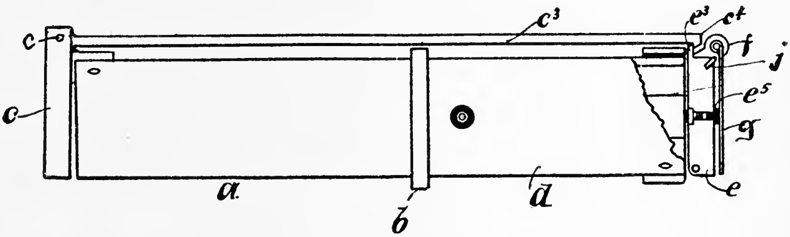


Fig. 154.—Self-Restoring Drop.

but also may reduce the cost of the operation of the exchange by enabling fewer operators to handle the system. There are, however, many who contend that the greater part of an operator's time is necessarily taken up in talking or listening to the subscriber in order to ascertain his wishes, and that while she is doing this she may restore the drops by hand without loss of time. Notwithstanding this, however, the number of exchanges using self-restoring drops is rapidly increasing, and many inventions have recently been made and put into practice to bring about this result.

Brief mention has already been made of the electrically restoring switch-board drops used to a large extent by the American Bell Telephone Company. The details of such a drop are shown in Figs. 154, 155, and 156. In Fig. 154, *a* is a tubular electromag-

net, carrying on its rear end an armature, *C*, pivoted at *c*, which armature carries an arm, c^3, which projects forward and is provided with a catch, c^4, on its extremity. So far the arrangement is almost identical with that of the Warner tubular drop already described. A second tubular electromagnet, *d*, is secured to the front of the plate, *b*, which also supports the magnet, *a*. This second magnet has its poles facing the front of the board. An armature, *e*, is pivoted at its lower side by the pivots, e^1 and e^2, shown in Fig. 156. The catch, c^4, on the rod, c^3, is adapted to engage a lug, e^3, on the armature and retain it in its vertical position. Pivoted on the bracket, *f*, which is insulated from the magnet by the strip of insulating material, f', is a light shutter, *g*. The tendency of the armature, *e*, when released is to fall outward, and in so doing it presses against the light shutter, *g*, just below its pivotal point, and forces it into a horizontal position.

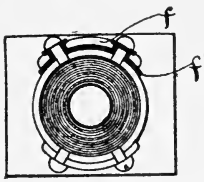


Fig. 155.—Self-Restoring Drop.—Sectional View.

The coil of the electromagnet, *a*, is usually termed the line coil, and is included in the circuit of the line wire. The coil of the electromagnet, *d*, termed the restoring coil, is in a local circuit containing a battery which is closed by the insertion of a plug into the spring-jack of the line belonging to that drop.

Various arrangements associating drops of this type with the line circuits and with the local circuits at the exchange have been devised and put into practical operation with almost unqualified success. The arrangement in Fig. 157 is typical, and at the same time shows a very interesting improvement designed for saving battery power in the exchange. The ordinary arrangement of subscriber's circuit is shown, and it will be noted that the actuating coil, *a*, is bridged across the two sides of the line wire. The coil, *a*, of course, is necessarily wound to about 500 ohms resistance to prevent short-circuiting the voice current. Two sleeves or thimbles, *k* k^1, are shown on each jack of the line, the inner ones, *k*, of which are shown connected permanently together and grounded through a battery, k^3. The outer thimbles, k^1, are connected together, and are usually connected to the ground directly through the restoring coil, *d*. When with this arrangement a plug is inserted, the two thimbles of the jack, *k* k^1, are short-circuited by the sleeve on the plug, and the circuit through

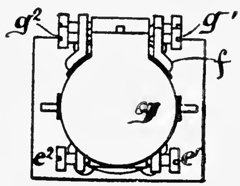


Fig. 156.—Self-Restoring Drop.—Front View.

the actuating coil is thus closed through the battery, k^3. This pulls the armature, e, back until it engages the catch, c^4, and thus allows the shutter to swing into its normal position. Any subsequent currents coming over the line wire will fail to operate the drop, for the coil, d, will not allow its armature, e, to fall against the shutter, g, while the plug is in the jack of that line. This arrangement has been found to be subject to one somewhat serious objection, viz., the severe use of the battery, k^3, owing to the fact that it is on closed circuit through the low-resistance coil, d, as long as the plug is in its socket. In order to overcome this objection the plan shown in Fig. 157 was devised by Scribner. The wire leading from the thimble, k^1, to the restoring coil is run to the pivot of the shutter, g, as is shown, and the side of the restoring coil which is not grounded is run to the armature, e. This connection is very clearly shown in Fig. 157. The shutter, g, is normally insulated from the armature, e, by virtue of the small hard-rubber bushing, e^5, and the insulation, f^1, between the bracket, f, and the magnet, d. This construction has been shown in Fig. 154. When, however, the armature, e, falls forward, a small lug or platinum contact point, j, on the upper side of the armature strikes against and makes contact with the armature, g, thus closing the circuit between them.

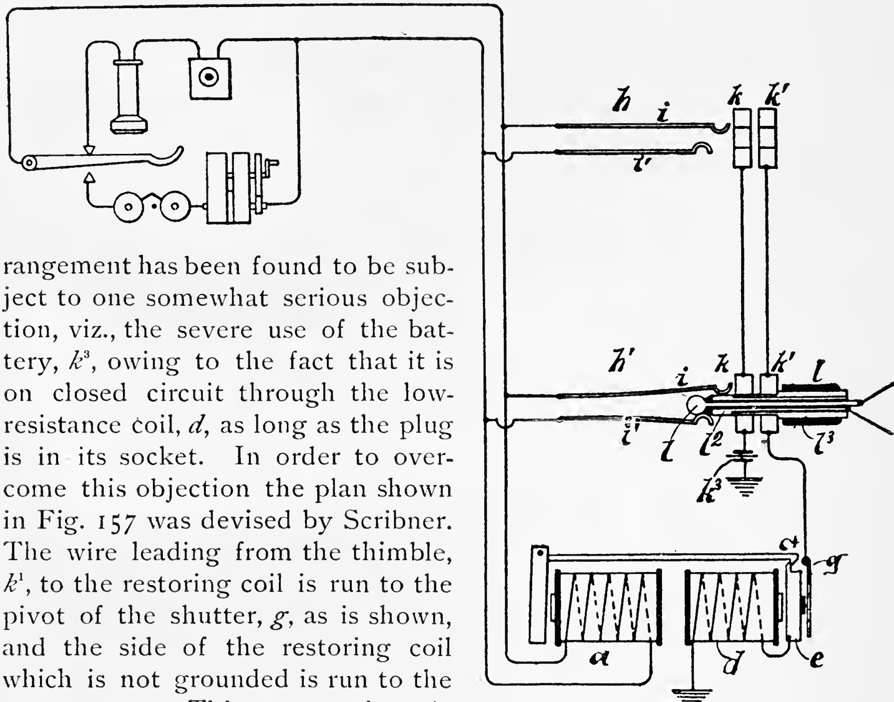


Fig. 157.—Circuits of a Self-Restoring Drop.

If no plug is inserted into the jack of the line, the local circuit through the battery, k^3, will be open at the jack, and the armature will be allowed to fall forward when released by the catch, c^4. As soon, however, as a plug is inserted the local circuit through

the battery will be completed, it being closed both at the armature contact point, *j*, and at the jack. This will send an impulse of current through the restoring coil, and pull the armature back until caught by the catch, c^4. This same movement of the armature opens the circuit at the contact, *j*, and thus no battery power is wasted. A subsequent calling signal upon the line circuit while the plug is in the jack will tend to operate the annunciator, but almost as soon as the shutter, *e*, is released the local circuit will be closed at the contact point, *j*, thereby re-attracting the armature to its normal condition and preventing it from falling to actuate the shutter.

An entirely different form of self-restoring drop has come into very general use among the companies operating in the United States in opposition to the American Bell Telephone Company.

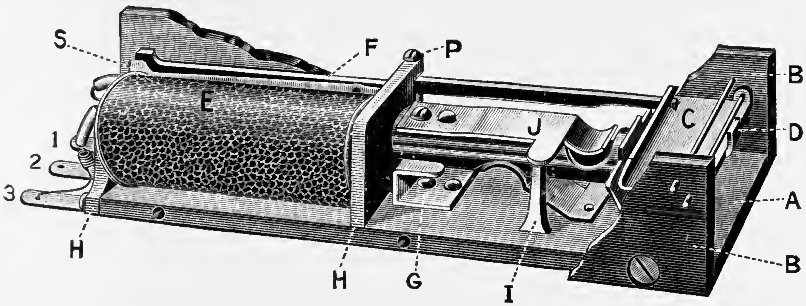


Fig. 158.—Western Telephone Construction Co.'s Drop and Jack.

These are what are termed mechanically self-restoring drops, and in order that the drop may in each case be in close proximity to the jack the two are usually associated in one piece of apparatus.

The combined jack and drop has, in some cases, given good satisfaction in practice, and when properly made possesses some advantages not to be found in the electrically restoring type of drop. In the first place, all the additional coils on the drops, and the additional contacts on the spring-jacks and the additional wiring between the two, are entirely done away with. Another advantage, and one that is usually overlooked, is that when the drop falls the eye of the operator is attracted directly to the point into which she must insert her plug; while in the forms where the jacks and the drops are entirely removed from each other the operator must first look at the drop, ascertain its number, and then look for the corresponding number of jack on the board below. This very materially increases the ease of op-

eration, and consequently tends in itself to give more rapid service.

The drop and jack of the Western Telephone Construction Company was the first of this type to come into extended use. It is shown in Figs. 158 and 159, Fig. 158 showing the shutter in its normal position, and Fig. 159 showing it after it has been thrown down by an incoming call. In these figures the arrange-

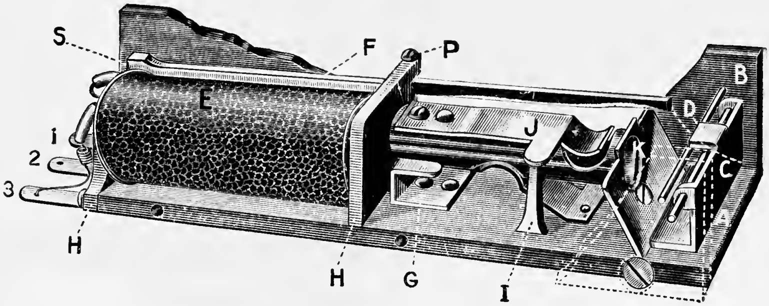


Fig. 159.—Western Telephone Construction Co.'s Drop and Jack.

ments are such that the spring-jack, *J*, of a line lies directly in front of the actuating coil, *E*, belonging to that line, and the shutter, *C*, so arranged as to fall directly in front of the jack when released by the armature, *F*. The combined jack and drop are mounted on a base of hard rubber, *A*. The armature, *F*, is pivoted in the front head, *H*, of the electromagnet by the pivot screw, *P*, and has a forwardly extending arm adapted to support the shutter, *C*, in a horizontal position. A small leaf spring, *S*, normally holds the rear end of the armature away from the rear head, *H*, of the coil and in a position to be attracted by that head when a calling current is sent through the coil. The attraction of the rear end of the armature causes its front end to move sidewise and release the shutter, thus allowing it to fall into a vertical position and display itself to the view of the operator, as shown in Fig. 159.

In order to make a connection with the line the operator inserts her plug directly against the shutter, which is down, and in so doing restores the shutter to its normal horizontal position by a positive mechanical movement. The plug is guided into its jack by the shield or guide-plate, *K*. In entering the jack the spring, *J*, is lifted off the anvil, *I*, by the sleeve of the plug, thus breaking the connection through the coil of the drop. The spring, *J*, makes contact with the sleeve of the plug, while the spring shown on the under side of the jack makes contact with

the tip of the plug, thus continuing the tip and sleeve sides of the line to the two strands of the plug cord.

These drops and jacks are mounted into a sort of an "egg case" composed of the bases, *A*, and the hard-rubber side-pieces, *B B*. These egg cases usually contain one hundred compartments, ten wide and ten high; $1\frac{1}{8}$ inch is allowed in each direction between the centers of the jacks. The wires on which the shutters are hung are common to each horizontal row of ten, and the other wire shown is also common to each row of ten. These two wires form the terminals of the night-alarm circuit, and when a shutter is down the lug, *D*, on the shutter strikes against the rear wire, thus making connection between the two and causing the night bell to ring.

This combined jack and drop has given very good service in a large number of cases, but has nevertheless several rather serious

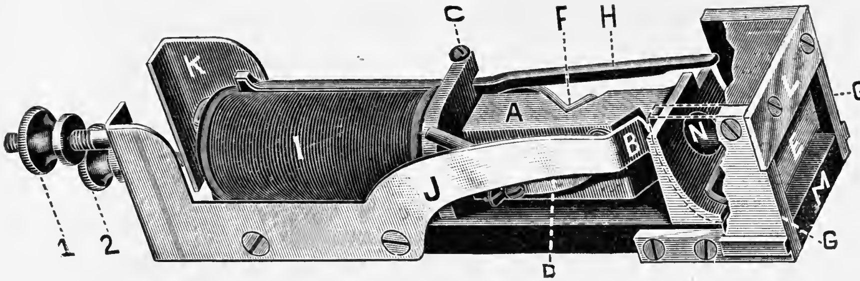


Fig. 160.—Western Telephone Construction Co.'s New Drop and Jack.

faults, chief among which may be mentioned the fact that the tip- and sleeve-springs are necessarily very short and therefore liable to lose their tension; and also the fact that the various parts of the jack are mounted separately upon a hard-rubber block, and therefore the entire jack is not as rigid as if all were mounted upon a solid brass block. These defects have been to a large extent removed in a more recent form of apparatus put on the market by this company, and designed by Mr. A. M. Knudsen. In this, shown in Fig. 160, the general arrangement of the various parts is the same as in the type just described, but the springs are made longer by mounting them upon the sides of the jack base, and in fact making them continuations of the frame itself. The rear portions of these springs are provided with thumb-screws, 1 and 2, which pass through a back panel in the board and secure the entire drop and jack in position, and at the same time afford means for connecting with the tip and sleeve sides of the

line. The jack-tube *A*, and the shield for guiding the plug into the socket are formed from a single casting of brass firmly secured to the jack base, *M*, thus providing a much more rigid construction than that shown in Figs. 158 and 159. The shutter, *E*, operates in the same manner, it being shown in its exposed

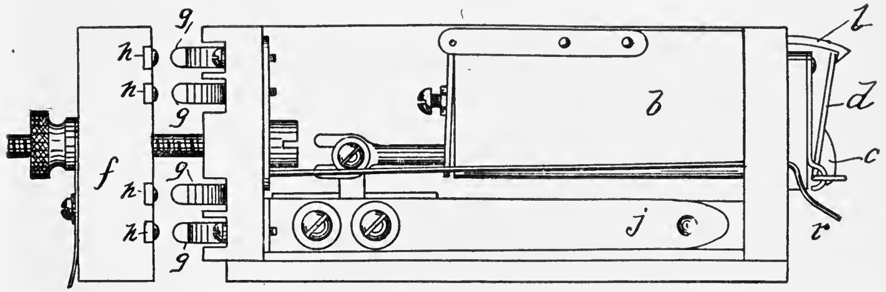


Fig. 161.—Side Elevation American Drop and Jack.

position, the path through which it swings being indicated by the curved dotted line.

Great sensitiveness can never be attained with this drop, because the shutter rests upon the armature rod in such manner as to bear upon it with its entire weight. It can therefore only be released by a considerable effort on the part of the armature,

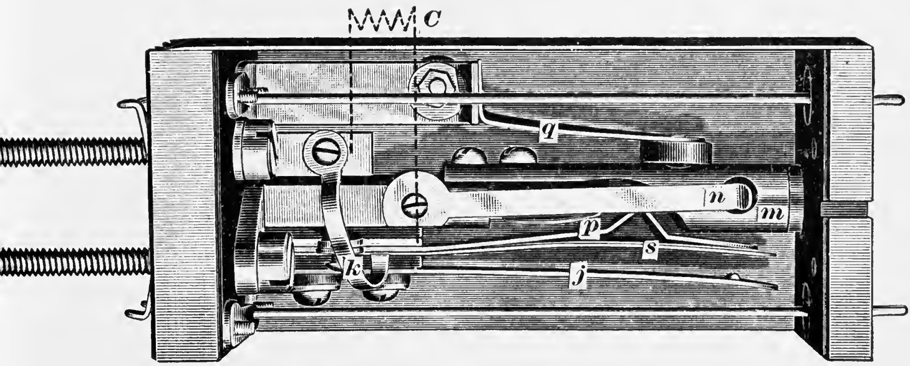


Fig. 162.—Top View, with Coil Removed.

this effort being due to the friction between the shutter and the armature rod.

Another form of mechanically self-restoring drop is that no manufactured by the American Electric Telephone Company. In this drop, which is shown in Figs. 161, 162, and 163, the actuating coil is mounted directly above the spring-jack. The coil is incased on all sides except the top in a sheet-iron shield or

box, *b*, for lessening the amount of induction between adjacent drops. The armature of the magnet is pivoted at the rear of this shield and carries a forwardly projecting lever, *l*, which in turn carries on its forward end a catch for holding the shutter, *d*, in its

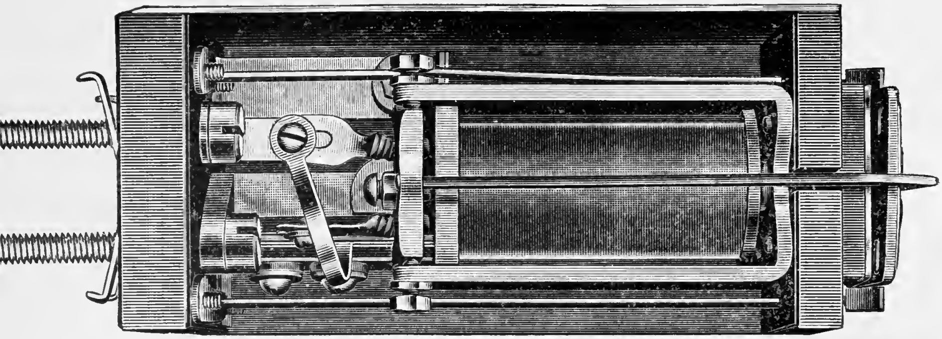


Fig. 163.—Top View, with Coil in Place.

vertical position. On the shutter is placed a cam, *c*, which when the shutter is down lies in front of the opening of the jack. The plug shown in Fig. 164, carries an enlargement or collar, *k*, which collar engages the cam, *c*, on the shutter when the plug is inserted into the jack, and forces the shutter into its normal position.

No cut-out is provided for the coil, which is therefore left in series in the line during a conversation. The coil therefore

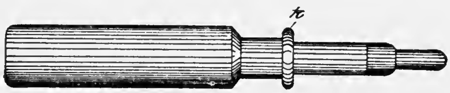


Fig. 164.—Plug for American Drop and Jack.

serves as a clearing-out drop, and when so actuated the cam on the shutter falls in front of the collar on the plug. When, therefore, the plug is withdrawn from the jack, after the clearing-out signal has been sent, the cam again engages the collar on the plug and the shutter is restored again to its vertical position.

The entire structure of the combined drop and jack is removable from the board by taking the thumbnuts off the screws shown in the rear. These screws pass through the board forming the frame of the switch-board, and serve not only to hold the jack and drop in place, but to establish a connection between the line wires and the line springs of the jack. Small springs, *g g*, on the back of the jack register with corresponding contacts on the front side of the backboard, thus serving to extend the night alarm and

generator circuits from the jacks to the other parts of the switch-board. By this means the proper connections are automatically made when the jack is slipped in place.

The drop illustrated in side elevation in Fig. 161 is of the common-return type, and is therefore provided with but one line terminal. Figs. 162 and 163 show a later pattern adapted for metallic circuits and operating in the same general manner so far as the restoring of the shutter is concerned. Fig. 162 is a horizontal view with the annunciator removed, showing the arrangement of the various parts of the jack. In this figure the coil is indicated at *C* in order to better illustrate its circuit connections. Fig. 163 is a similar view of the complete apparatus, with the annunciator in place. The various circuits of the apparatus will be understood most readily by considering Fig. 162. In this *m* is the jack-tube which is directly connected with the line terminal screw, *L*. This tube is provided with a spring, *n*, which serves to establish a firmer contact with the sleeve of the plug when inserted into the jack. The coil, *C*, of the annunciator is connected directly between the line terminal screw, *L'*, and the tip-spring, *p*, the sharply bent portion of which spring is adapted to make contact with the tip of the plug when inserted into the jack. A spring, *q*, is connected by means of one of the small springs, *g*, in Fig. 161 to one terminal of the generator. This spring, *q*, is provided with a metallic pin which projects through a hole in the jack-tube, *m*, to a sufficient distance to make contact with the enlarged sleeve of the plug when the latter is inserted into the jack to its fullest extent, but not far enough to engage the tip contact when the plug is in its normal position in the jack. By this means, when the plug is inserted as far as it will go into the jack, one terminal of the generator is connected with the line terminal screw, *L*, by means of the sleeve spring, *n*, and the generator spring, *q*, both coming in contact with the sleeve of the plug. The other terminal of the generator is connected with the spring, *j*, through the medium of one of the small contact springs, *g*, on the back of the jack. Upon pushing the plug as far as it will go into the jack, the tip-spring, *p*, rides upon the insulated portion of the plug, thus pressing the thin spring, *s*, which lies parallel with, but is insulated from, the tip-spring, into engagement with the generator spring, *j*. This connects the line terminal screw, *L'*, with the generator-spring, *j*, through the medium of the strap conductor, *k*, and the calling current is therefore sent to line. It will be noticed that the path by which the generator current passes to line is not through the

coil of the annunciator, but through the strap, *k*, instead ; and it will also be noticed that the tip conductor of the plug is disconnected from the tip-spring, *p*, before the contact is made with the generator-spring, *j*, and therefore no calling current will pass back over the cord circuit through the operator's telephone. Upon removing the pressure from the plug, a coiled spring in its handle forces it out of the jack for a short distance until it assumes the normal or talking position.

Many other forms of mechanically self-restoring drops have been devised, but the two types here described have come into by far the most general use.

As an illustration of the saving which either the electrically or mechanically self-restoring drops bring about in the operation of switch-boards, certain boards may be cited that have been put into use where the drops are of the ordinary hand-restoring type, placed in series in the line and not cut out by the insertion of the plug. In the establishing and disestablishing of a connection between two subscribers, the operator was required to restore a switch-board drop four different times. First she restored the drop of the line of the calling subscriber, next when she sent a calling current to the line of the called subscriber this current passed through the drop of that line, causing it to fall. This she also restored by hand, and lastly when one or both of the subscribers rung off, the drops of each line fell and were restored by hand, thus making four in all. Such switch-boards are, of course, necessarily slow. Moreover, they are almost invariably much larger and more cumbersome than the more modern types, but even these drawbacks have not interfered with their giving satisfactory service in some cases in small exchanges.

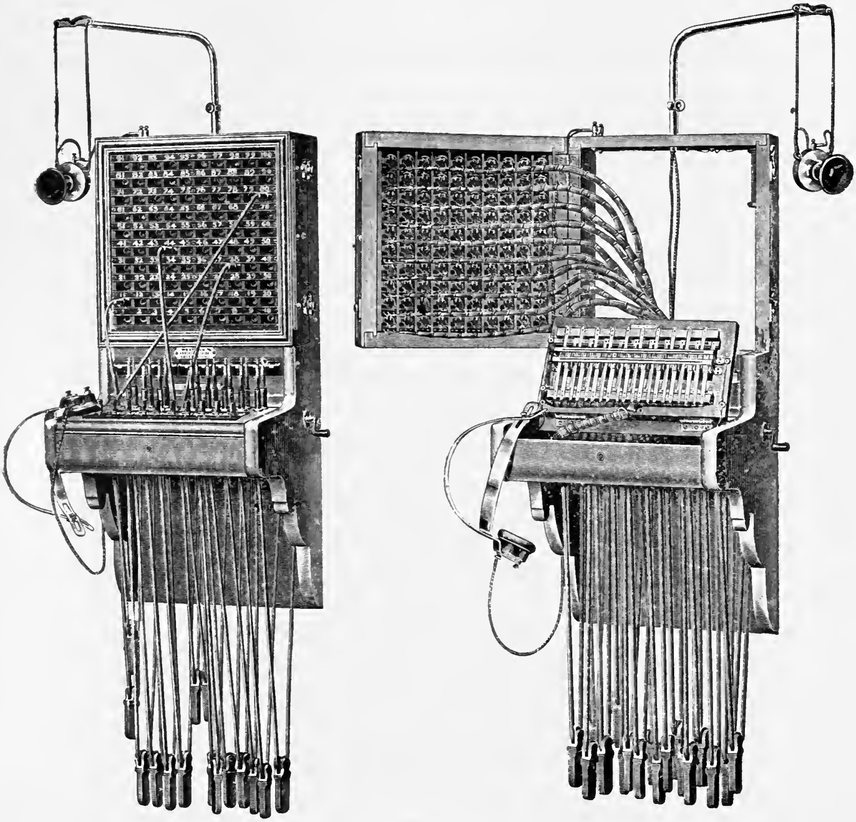
CHAPTER XVII.

COMPLETE SWITCH-BOARDS FOR SMALL EXCHANGES.

We have considered so far the circuits, and also the various parts, including drops, jacks, circuit changers, etc., which go to make up switch-boards for small exchanges. In this chapter will be considered a few of the more common types of such switch-boards in their completed forms. The matter of properly constructing the various parts of switch-boards is hardly of more importance than that of properly organizing these parts into a complete working system by means of their arrangement in their proper circuits. The main points to be sought in the mounting of the various parts of switch-board apparatus so as to form a complete working organization, are that the arrangement may be such as to facilitate the work of the operator; that all parts liable to get out of order shall be readily accessible for repairs; that all wiring shall be systematically arranged in a manner that shall preclude the possibility of short circuits, crosses, or open circuits; that the circuits of the various lines shall be free from inductive influence upon or from the other circuits; and that the framework upon which the working parts are mounted shall not by virtue of its shrinking or warping affect the proper operation of these parts.

In Fig. 165 is shown a front view of a 100-drop switch-board manufactured by the Western Telephone Construction Co. This board is designed to be mounted directly upon the wall or upon a partition in the exchange. It is provided with 100 combined drops and jacks of the type shown in Figs. 158 and 159. These drops and jacks are built up between hard-rubber partitions which form a structure not unlike an egg packing case, each drop and jack occupying a separate cell. Below the line-drops is placed a row of ten clearing-out drops included in series in the tip side of the cord circuit. This drop is provided with a non-inductive winding, and also with a thin metal shield of magnetic material, which together effectually prevent cross-talk between two adjacent drops. It may be said, however, that the non-inductive winding, while it accomplishes the object for which it was designed, *i. e.*, the elimination of cross-talk, also greatly re-

duces the efficiency of the drop, but not to such an extent as to spoil its utility. The plugs are arranged in two rows of ten on the horizontal portion of the table, and in front of them is the



Figs. 165 and 166.—" Western " 100-Drop Wall Switch-Board.

row of circuit-changing levers, which operate as described in Chapter XV.

The entire case containing the line-drops is hinged on the framework of the board, as is also the key table, allowing the board to be opened up, as shown in Fig. 166, for the purpose of facilitating repairs. This figure shows the method of cabling the board, the line wires being formed into ten separate cables, one for each horizontal row. These cables are formed of No. 22 B. & S. guage tinned copper wire arranged in twisted pairs, the separate wires being colored red and blue. The insulation of these wires is composed of a single wrapping of silk upon which is laid two wrappings of cotton. The various wires leading to

the under side of the key table are formed into a tightly laced cable which is provided with a knee, as shown below the left-hand

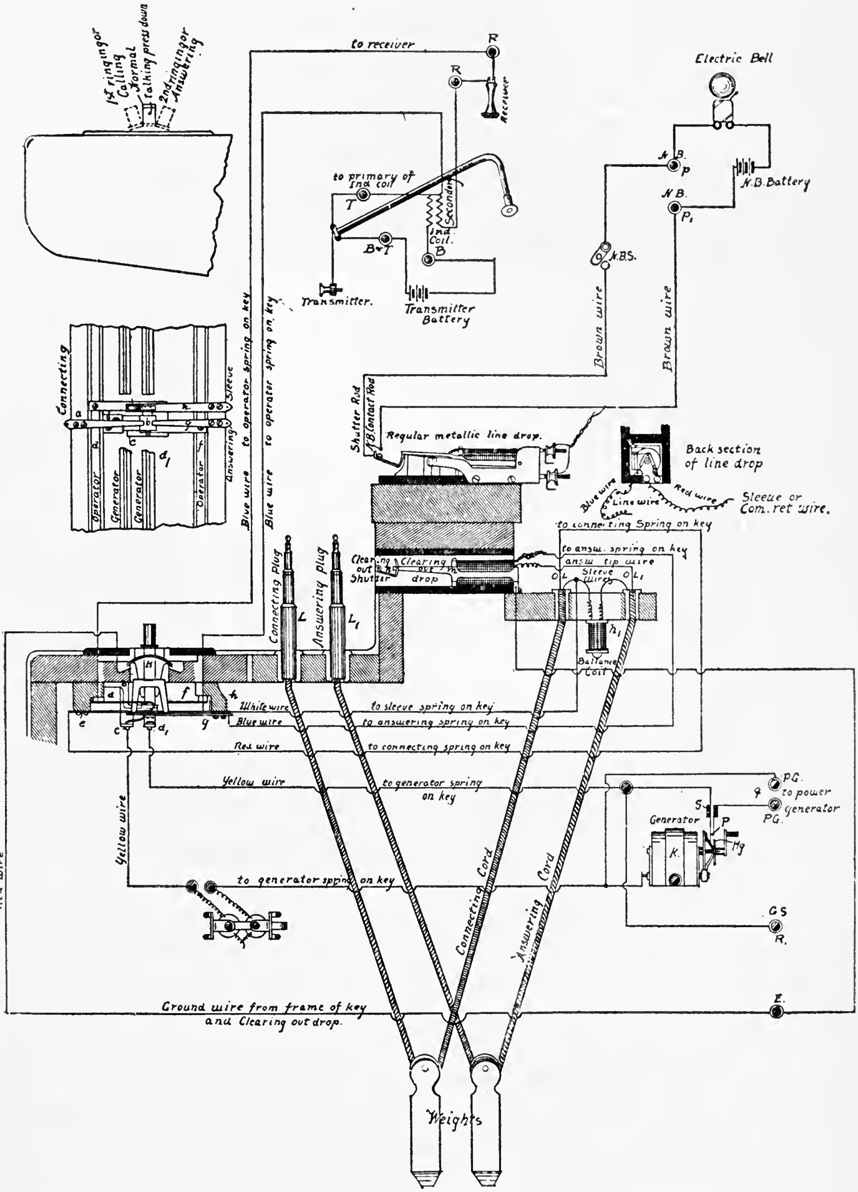


Fig. 167.—Circuits of "Western" 100-Drop Board.

portion of the key table in Fig. 166, which knee is for the purpose of allowing a free movement of the key table upon its hinges

without bending the various wires of the cable to such an extent as to cause breakage. The switch-board cords are provided with a spiral wrapping of wire and are held taut by means of small pulley weights, clearly shown at the bottom of the figure.

At the right-hand portion of the cabinet is placed the crank of the hand generator, the generator itself being mounted upon a shelf within the switch-board cabinet. It is customary in most

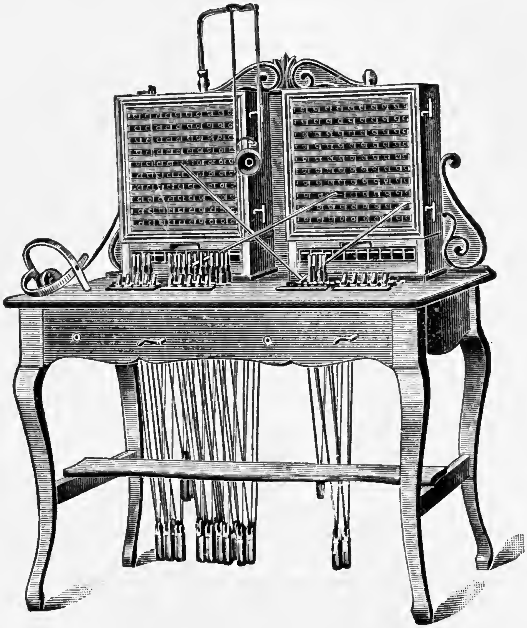


Fig. 168.—" Western " 200-Drop Table Switch-Board.

switch-boards to provide a hand switch by means of which, when the power generator is disabled or stops running, the hand generator may be switched into circuit. The necessity of this switch is overcome in this switch-board, the switching operation being performed automatically by the turning of the hand generator crank. Thus, while the hand generator is not in use, the generator terminals of the ringing keys are connected with the power generator. When, however, the hand generator crank is turned, the generator terminals of the ringing keys are disconnected from the power generator and automatically connected with the terminals of the hand generator. This arrangement is ingenious and very effective, and it relieves the operator's mind of all thought concerning the position of the generator switch. The circuits of this switch-board are shown in Fig. 167.

In Fig. 168 are shown two 100-drop sections of this switch-board mounted upon a table, in front of which either one or two operators may sit. The apparatus, circuits, and operation of this board are identical with that of the boards shown in Figs. 165 and 166. In case a subscriber whose line terminates in one section calls for a subscriber whose line terminates in the other section, the connection is made by reaching across the face of the boards with the plug to be used in connection. It may be said that this method of reaching across may be used with success in exchanges having as many as three or four hundred subscribers, provided the boards do not take up so great an amount of room as to render the reach too long. The reach is of course limited, not only by the convenience with which the operators can make it, but also by the length of the cords, and the length of the cords is necessarily limited by the height of the switch-board above the floor. As many as six of the switch-boards of the type shown in Fig. 165 have been used side by side in this manner, but of course better results would have been obtained had some of the trunking methods, which will be described later, been used.

A front view of a 100-drop switch-board of the Sterling Electric Company of Chicago is shown in Fig. 169, and a rear view of the same board in Fig. 170. In this the drops are mounted in the panels at the top of the board in vertical rows of ten each. In a panel directly below the drops are the line jacks, connected with the drops by means of wires formed into vertical cables and shown in Fig. 170. The drops in this board are not properly of the self-restoring type, but are provided with an attachment which accomplishes the resetting of the shutters with little, if any, loss of time. Below each of the vertical rows of drops is a knob attached to a sliding rack in such manner that when it is pressed the entire rack is raised, thus restoring any shutter which may be down in that particular vertical row. As these knobs are arranged close to the spring-jacks they are within easy reach of the hand of the operator while she is inserting a plug. The plugs are arranged in two rows, being staggered so as to be more easily reached by the operator. The panel upon which they rest is of sole-leather, which material has proven its ability to withstand wear, and at the same time offers the additional advantage of not injuring the plugs when they are dropped upon it. The ringing and listening keys of the type shown in Fig. 145 are used in this board.

In this board no clearing-out drops are used, and the plugs

are so arranged that one in each pair will cut out the line-drop when inserted in a jack, while the other will not; this difference being brought about by making the answering plugs shorter than the calling plugs. As a result, the drop of the line with which

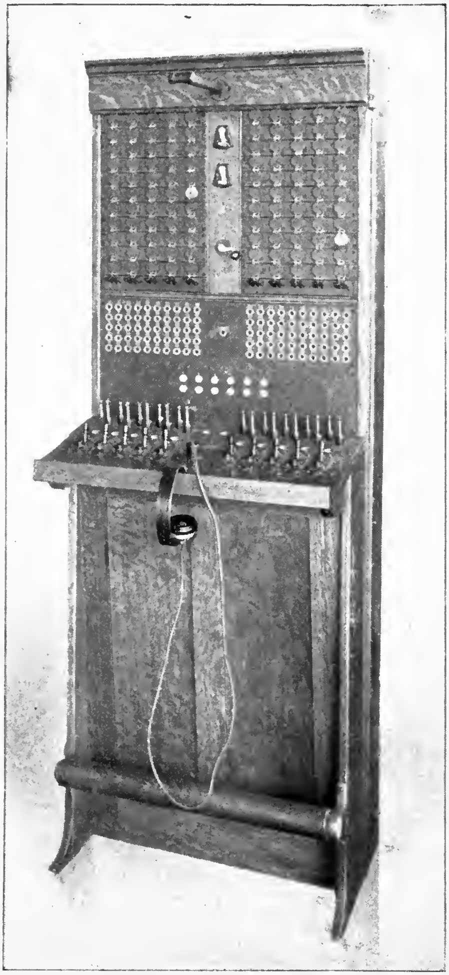


Fig. 169.—Sterling Electric Co.'s 100-Drop Switch-Board.

the answering plug is connected is left in circuit to serve as a clearing-out drop, while the drop of the line with which the calling plug is connected is cut out of the circuit. Another very desirable feature of this board, and one which could be followed by all manufacturers, is the means which are provided for com-

pletely inclosing all of the wiring and mechanism of the switch-board from behind, so as to prevent dust from settling upon them.

In Fig. 171 is shown the so-called express switch-board of the

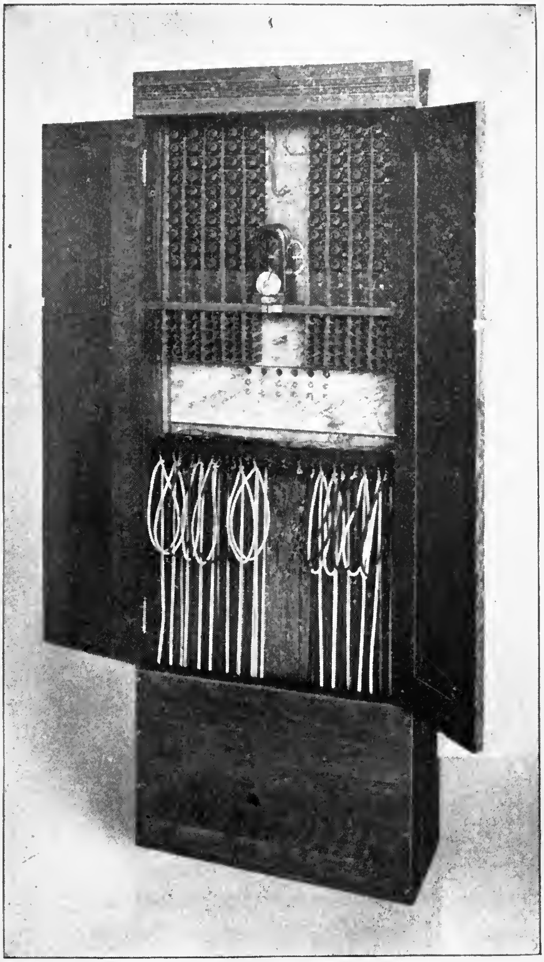


Fig. 170.—Sterling Electric Co.'s 100-Drop Switch-Board.

American Electric Co. In this the drops and jacks are of the combined self-restoring form shown in Figs. 161, 162, and 163. They are arranged in ten rows of ten each, and by means of the thumb-nuts that engage the line terminal screws at the back of each drop and jack are held in place within a cabinet. By the

removal of these thumb-nuts any one of the combined drops and jacks may be withdrawn from the front of the board without disturbing the line connections on the rear. No separate clearing-out drops are used, as the line drops serve the purpose, as already described. In front of the plugs on the horizontal table are arranged the listening keys, which are sim-

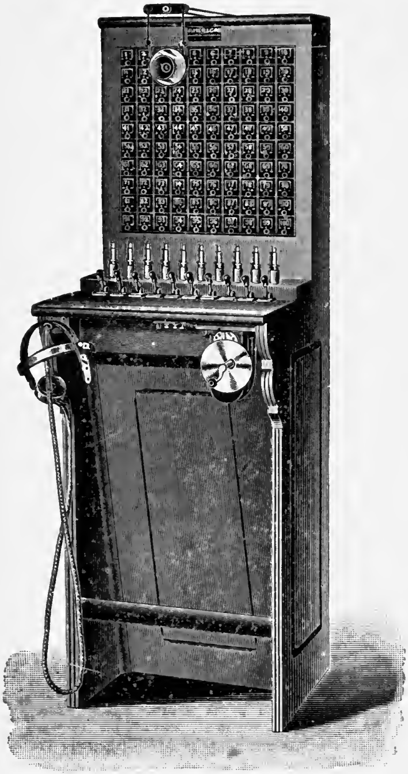


Fig. 171.—American Express Switch-Board.

lar in construction to that shown in Fig. 149. The hand generator is mounted on the under side of the front of the key table within easy reach of the operator. The operation of this board is as follows: when a line-drop falls the operator inserts one of the plugs in the row farthest from her into the jack, this action automatically restoring the shutter by means of the collar on the plug engaging the cam on the under side of the shutter. The listening key is then depressed, in order to find out the wants of the subscriber calling. Having found this, the operator inserts the mate of the plug into the jack of the called

subscriber and presses it in as far as it will go, at the same time turning the hand generator, if no power generator is used. This sends calling current to the line of the called subscriber, after which the operator releases the calling plug which springs out of the jack to a sufficient extent to disconnect the calling generator and re-establish connection between the line and the cord circuit. When the subscribers are through talking they ring off, and the line-drops are again actuated, and are restored automatically by the withdrawal of the plugs from the jacks.

CHAPTER XVIII.

LAMP-SIGNAL SWITCH-BOARDS.

In all of the telephone exchange systems so far outlined the various signals for attracting the attention of the operator have been given by some form or another of electro-mechanical annunciators, of which those of the self-restoring type represent the highest development. An entirely different class of signals has recently come into general use, especially by the Bell Company, namely, the incandescent lamp or luminous signal, as it is termed. The use of the incandescent lamp as a signal in telephone work was probably first proposed by Mr. J. J. O'Connell of Chicago.

The advantages of the incandescent lamp over the electro-mechanical signal are many, and among them may be mentioned the following: First, they are capable of attracting the attention of an operator with more certainty than the ordinary mechanical shutter ; second, they are entirely free from mechancal complication ; third, they are much more compact than even the simplest electro-mechanical signals ; fourth, they are entirely automatic in their operation, being always restored to their normal condition by a cessation of the current through them ; fifth, by the use of various-colored glass in front of them they may be used in the same board as indicating different kinds of information ; sixth, they are easily replaced when destroyed ; and seventh, they are cheaper than the high-grade tubular drops now in such common use. Against these advantages must be cited the somewhat serious disadvantage brought about by the apparent inability of lamp manufacturers to produce a uniform grade of miniature lamps. Thousands of lamps furnished to operating companies have after short trial proved utterly unfit for use. The difficulty in procuring good lamps has in some cases caused the abandonment of the lamp signal system.

Obviously there are two different methods of associating incandescent lamps with the circuits of the subscribers' lines. The first of these, and without mature consideration the most desirable, is to place the lamp directly in the circuit of the subscriber's line and operate it automatically by a change in resist-

ance in the line, brought about by the removal of the subscriber's receiver from the hook. The second is to have the lamp in a local circuit controlled by a relay directly in the line circuit, which relay may be operated by an ordinary subscriber's magneto-

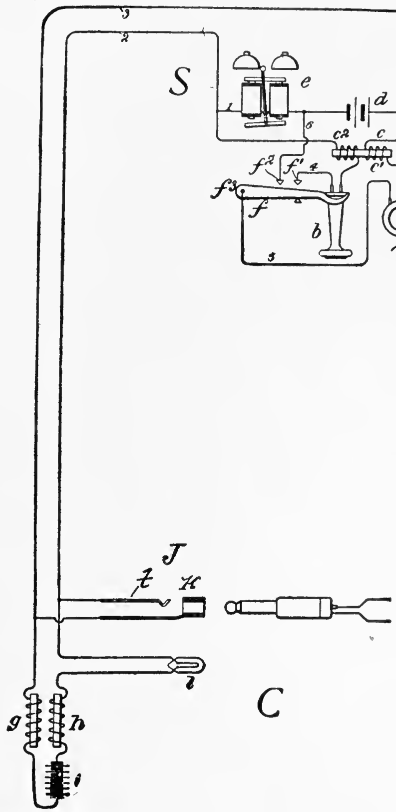


Fig. 172.—Lamp Signal System.

generator or by a source of current at the central office thrown into action by a change of resistance at the subscriber's station.

A system using the first method is shown in Fig. 172, in which the subscriber's apparatus is shown at *S*, and the central-office apparatus at *C*. The line wire, 2, forming one side of a metallic circuit, is connected with the tip-spring, *t*, of the jack, *J*, and passes through an incandescent lamp, *l*, and through an inductive resistance, *h*, to one pole of a battery, *i*. The other side, 3, of the metallic circuit passes through an inductive resistance, *g*, to the other pole of the same battery. When the subscriber's receiver is on its hook the circuit at the subscriber's station be-

tween the two sides of the line wire is completed only through the high-resistance call-bell, *e*, and as this bell has a resistance of about 1000 ohms, the current from the battery, *i*, through the line circuit is not sufficient to illuminate the lamp, *l*. When, however, the subscriber's receiver is removed from its hook a circuit of low resistance is closed in parallel with the bell magnets, *e*, this circuit including the secondary winding, c^2, of the induction coil, and the receiver, *b*, in series. As this circuit may readily be made less than 40 ohms, sufficient current will be allowed to flow from the battery, *i*, to illuminate the signal, and thus attract the operator's attention. Another feature of this system, and one which it was not the purpose of this chapter to illustrate, but which, owing to its ingenuity, should be mentioned in passing, is the peculiarity of the arrangement of the battery, *d*, with respect to the circuits of the subscriber's station. It will be obvious that whatever current passes through the bell magnets, *e*, from the battery, *i*, at the central office, must also pass through the battery, *d*. This consists of two cells of storage battery of the Planté type. Whenever the apparatus at the subscriber's station is not in use this battery will therefore be receiving a charge from the central-office source, the strength of the latter and the resistance of the circuits being so proportioned that the storage cell will receive a constant charging current of about .02 of an ampere. When the subscriber's apparatus is put in use, however, the battery is thrown in a local circuit including the primary winding, c^1, the transmitter, *a*, and the contact point, f^2, and will then perform the functions of an ordinary primary battery in connection with the transmitter. The chief novelty in this system consists in the alternative function which this battery, *d*, may perform. It is well known that if a storage cell of the Planté type becomes almost or quite discharged it will develop a counter E. M. F., when a current is sent through it in the direction necessary to charge it, and that this counter E. M. F. will be very nearly equal to the E. M. F. of a similar cell fully charged. Supposing, now, that from some cause or other the cell, *d*, becomes discharged to such an extent that it is incapable of furnishing enough current to operate with the transmitter, *a*, in the usual manner. In this case, when the receiver is raised, the current from the battery, *i*, at central, which tends to pass through the storage battery, will meet with a considerable counter E. M. F., which will compel most of the current to pass through the secondary, c^2, receiver, *b*, wire, 4, wire, 6, contact, f^2, wire, 5, transmitter, *a*, primary coil, c^1, and to the line wire, 3.

The transmitter, *a*, will therefore receive current from the battery, *i*, sufficient to operate it, and yet it will be operating with all the advantages to be derived from a local circuit and induction coil; for, although the current operating it comes from the central office, any fluctuations in this current caused by the transmitter, *a*, will pass through the low-resistance battery, *d*, which will act in this case very much in the same manner as a condenser. This system is the invention of Mr. C. E. Scribner of Chicago.

To return now to the luminous signal feature, we find ourselves confronted with several rather serious objections; in the first place, the resistances of no two subscribers' circuits are the same, owing to the differences in the lengths of these circuits and other causes, and therefore either the resistances, *g* or *h*, or that of the bell magnets, *e*, will have to be varied in each case in order to insure the proper amount of current passing through the lamp, *l*. This is a feature easy to overcome, and a much more serious one is that arising from crosses between two line wires from any source whatever, such a cross, of course, always subjecting the lamp to an undue amount of current, and therefore burning it out. This latter objection has proved so serious as to cause the abandonment of the plan of including the lamp directly in the line circuit in nearly every case where it has been tried. Of course, for underground systems this objection is not such a serious one.

Passing now to the second method of associating the lamp signal with the line circuit, reference will be made to Fig. 173. This shows the circuits of three subscribers' stations, S, S^1 and S^2, these circuits being connected with the central office by the metallic circuits, 1, 2. The line wire, 1, in each case passes to the sleeve-spring, d^2, of the spring-jack, J, and thence through the relay contacts, c^1, to the ground. The line wire, 2, passes in a similar manner to the tip-spring, *d*, thence through the relay contacts, c^2, the winding of the relay, *b*, and the battery, *a*, to the ground. The signal lamp, *e*, is in each case included in a local circuit containing the contact, 4, of the relay, *b*, belonging to its line, and a battery, *f*, common to all lamps. The relay, *c*, of each line, which controls the contacts, c^1 and c^2, is known as the cut-off relay, and is included in a local circuit through the jack-thimble, d^1, and the plug contact, *m*, with the battery, *n*, whenever a plug, 1, is inserted into a jack for making connection with the line. The two sides of the line at the subscriber's station are permanently closed through a high-resistance bell and a

condenser, the latter having a capacity of about .75 microfarad, so as to allow the alternating currents from the calling generator

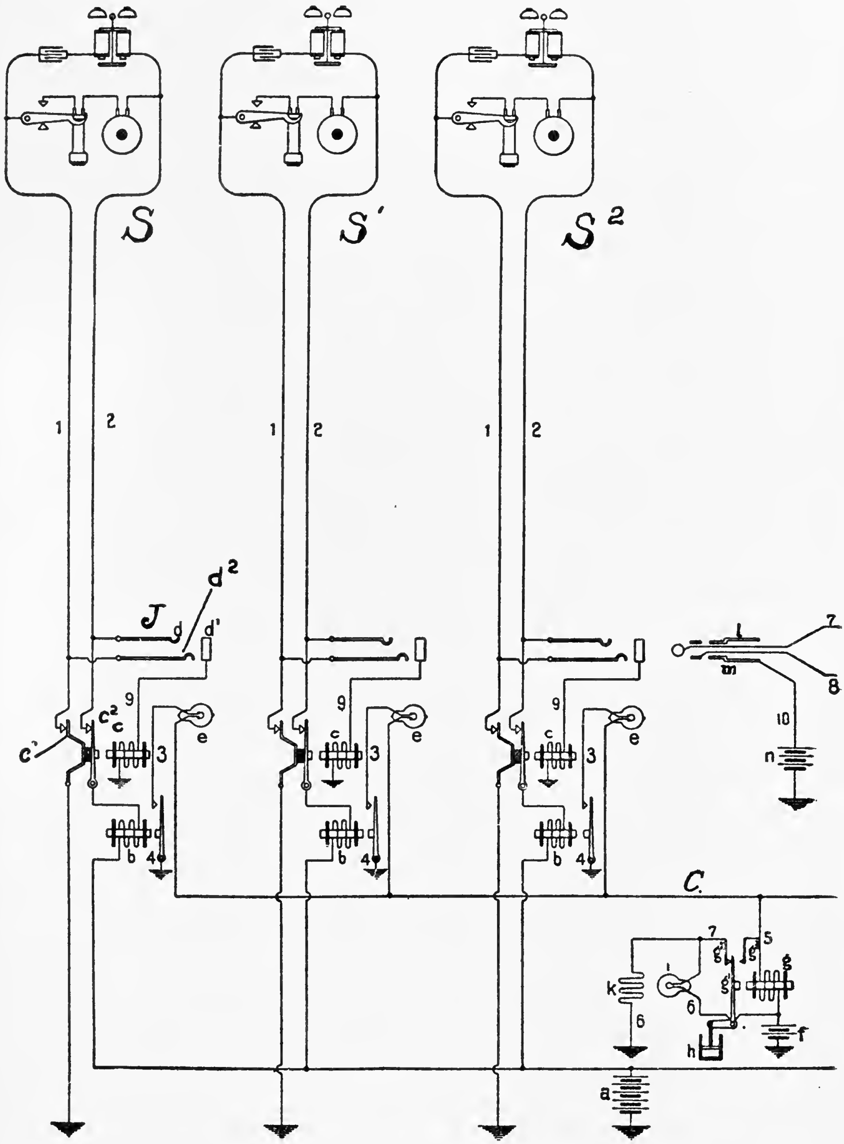


Fig. 173.—Lamp Relay System.

at the central office to pass through it and operate the call-bell in the usual manner. The high impedance of the call-bell magnets, however, prevents the short-circuiting of the voice currents

when the receiver is removed from its hook. The call-bell circuit therefore presents an open circuit to the direct current from the battery, *a*, thus normally insuring a condition of no current upon the line wire. When, however, the receiver at the subscriber's station is removed from its hook, a path of comparatively low resistance is formed between the two line wires, and a current proceeds from the battery, *a*, through the relay, *b*, contact, c^2, line wire, 2, to the subscriber's station, back by line wire, 1, through relay contact, c^1, and by ground to the opposite terminal of the battery, *a*. This current is sufficient to operate the relay, *b*, and, unlike the case where the lamp was used directly in the line wire, a considerable variation in the amount of this current is allowable. The operation of the relay, *b*, closes the circuit of the lamp, *e*, through the following path: from the battery, *f*, through the relay, *g*, wire, 5, common wire, *C*, lamp, *e*, wire, 3, relay armature, 4, and back by ground to the opposite pole of battery, *f*. For the purpose of clearness the relay, *g*, need not be considered at all at present, as it has nothing to do with the operation of the lamp, *e*, and we may therefore consider one pole of the battery, *f*, to be connected directly to the common wire, *C*. The closure of this circuit illuminates the lamp, *e*. The next step in the operation of the system is the insertion of the plug, *l*, into the jack of the line on which the signal is displayed. The insertion of this plug closes the circuit through the relay, *c*, over the following path: from the battery, *n*, wire, 10, plug sleeve, *m*, thimble, d^1, wire, 9, relay coil, *c*, to ground and back to the opposite pole of the battery, *n*. This causes the relay to attract its armature and break both of the contacts, c^1 and c^2, thus accomplishing a double purpose, the first of which is to break the circuit through the relay, *b*, and thus cause it to release its armature, 4, breaking the circuit through the lamp, *e*; and the second of which is to cut off both sides of the line circuit, 1, 2, beyond the spring-jack, *J*. This latter feature is a very important one, since it removes all difficulty from cross-talk and other troubles in the auxiliary circuits of the central office.

The circuits illustrated in Fig. 173 are substantially those in common use by the Bell Company in their lamp-signal exchanges, so far as the circuits of the relays and lamps are concerned. Several different modifications of the circuits at the subscribers' stations have, however, been used. The subscribers stations may or may not include local batteries, and the tendency of practice is now to do away with these entirely and to supply current

from central office for the operation of the transmitters as well as for all signaling purposes. This feature, however, will form the subject of a subsequent chapter.

The relay, *g*, and its associated apparatuses form a very interesting addition to the system as outlined. It is found desirable to use what are termed pilot lamps for certain groups of line lamps, for the purpose of attracting the operator's attention more surely to a signal on her board. If two or more signals are displayed at once, but one of them may attract the attention of the operator, who might therefore neglect the other. Pilot lamps are used in such connection that they remain lighted as long as any one of the line lamps in their group is lighted, and as they occupy a very conspicuous position and are as a rule brighter than the others they cannot escape the operator's attention. It is not desirable to put a relay for operating such a pilot lamp in the common wire, *C*, of the local circuits of the lamps, *e*, for the reason that the fall of potential or drop through such a relay would vary, according to the amount of current passing through it, and if several of the lamps, *e*, were operating at the same time, they would probably not therefore receive enough current to properly illuminate them. The relay, *g*, is therefore included in circuit with battery, *f*, and means are provided whereby its resistance will be short-circuited the instant it is operated. To accomplish this, the armature, g^1, makes contact with the point, g^3, as soon as it is attracted, thus short-circuiting the resistance of the coil, *g*. At the same time it breaks contact with the point, g^2, and thus allows the current to flow from the battery, *f*, through the lamp, *i*, and resistance, *k*, thus illuminating the lamp. In order that the armature, *g*, may not fall back against the contact point, g^2, as soon as the coil, *d*, is de-energized by being short-circuited, a small dash pot, *h*, is provided in connection with the armature to render its movements sluggish. Thus before the armature, g^1, has time to move very far away from the point, g^3, owing to its sluggish action, it will be at once attracted again, and the interval during which the resistance coil, *g*, is in circuit with the common wire, *C*, and the lamps, *e*, is so small that it does not have time to affect these lamps. This system is also due to Mr. Scribner, and both it and the one shown in Fig. 172 form interesting examples of the highly skillful manner in which he always solves his telephone problems.

Incandescent lamps for signaling purposes are commonly built for 10 or 20 volts pressure, the tendency being rather to increase

the voltage than to decrease it. At first lamps of 2 and 4 volts were used, but for various reasons, not the least among which was the trouble of securing proper contacts at the relay and switch points for such low voltages, the voltage was gradually increased to the above-mentioned figures.

Mr. A. V. Abbott of Chicago has recently given some interesting figures concerning the life of incandescent lamps in switchboard work, and mentions one case where a lamp was flashed over a million times without showing serious signs of deterioration. His tests seem to indicate that for general service in switch-board work the average lamp will live for a period of about 1200 hours, although in laboratory tests a much longer life has proved possible. He points out, as a result of his observations, that according to theory, the lamps used in subscribers'-line circuits should last about twenty-five years, and those in the cord circuits used as "supervisory" and clearing-out lamps, from one to two years. He also says that such a life has already been obtained in the cord-circuit lamps, but that it is doubtful if the theoretical limit for the line lamps will ever be closely approximated.

CHAPTER XIX.

THE MULTIPLE SWITCH-BOARD.

WHEN the number of subscribers in an exchange exceeds 400 or 500, the switch-boards so far considered become inadequate; for in order to afford room for the number of operators needed to properly handle all the connections, the board must be made of considerable width, and is thus too wide for the operators to reach across with their cords.

The multiple switch-board, which is designed to enable each operator to make any connection required without the aid of any other operator, and without the use of unduly long cords, is used in most of the large exchanges in this and other countries. The idea underlying the construction of multiple boards is very simple. In practice, however, the greatest complexity is met, but this is due entirely to the great number of repetitions of one comparatively simple circuit.

The boards are divided into sections, each section usually affording working room for three operators. Each line, instead of being provided with a single spring-jack or terminal, as on the boards used in small exchanges, is provided with a spring-jack on every section of the board, and with a drop or other visual signal on one section only. Each section therefore contains a spring-jack for every line entering the exchange, and also a number, usually 200, of line-drops. Suppose an exchange to have 3000 subscribers. The multiple board would then probably have 15 sections, each containing 3000 jacks, that is, a jack for each line. Each section would also contain 200 drops belonging to the 200 lines whose calls would always be received on that particular section. An additional jack, called an answering jack, is usually provided for each line on the particular section at which that line's drop is located. These answering jacks are placed in a separate panel at the lower part of the switch-board.

Before considering any particular form of multiple board it is probably well to describe in a general way the operation of the multiple board. When a subscriber calls the attention of the operator at whose section his drop is located, the operator plugs into the answering jack of that line with an

answering plug, and having switched her telephone into the cord circuit of that plug, ascertains the number of the subscriber desired. She then completes the connection with the subscriber called for by inserting the calling plug into the multiple jack of that subscriber's line, one of which is, of course, on her section.

As each section contains one multiple jack for every line in the exchange, it is evident that an operator will always be able to complete a connection with any subscriber who may be called for by any of the 200 subscribers whose drops are located at her section. During the least busy portions of the day one operator at each section usually suffices to handle all of the calls originating at that section. As the number of calls increases two operators may be placed at each section, and during the busiest part of the day three are usually required.

When three operators are seated at a section, the center one can reach all of the jacks on the section at which she works. The operator at her right cannot well reach the jacks on the extreme left-hand portion of that section, but she has within her reach a similar portion of the section at her right into which she may plug when necessary. In a similar manner, the operator at the left cannot well reach the jacks on the extreme right of her of her own section, but can reach with her left hand the jacks on the extreme right of the section at her left. Thus every operator has a multiple jack for each of the entire number of lines within her reach; the right-hand operator controlling the right-hand two-thirds of her own section, and the left-hand one-third of the section at her right, the center operator controlling her entire section, and the left-hand operator controlling the left-hand two-thirds of her section, and the right-hand one-third of the section at her left.

In order to prevent two or more connections being made to one line at different boards, some sort of a test system is necessary. It is therefore usually so arranged that when a line is "busy"—that is, when it is connected to some other line for conversation—an operator at some other board than the one at which the connection is made, in trying to connect another party to that line, will in some simple way be notified of the fact that that line is already busy. This is known as the "busy test" and on its efficiency to a great extent depends the operativeness of the multiple board.

In Fig. 174 are shown diagrammatically three lines passing through three separate sections in a multiple board. One side of each line—for instance, of line 1—passes in multiple

to all the contact rings, *b*, of a jack on each section. It then passes to one terminal of the line-drop, *d*. The other side of the line passes to the spring, *a*, in the jack belonging to that line at section 1. This spring rests against an anvil, *c*, to which a wire is connected which runs to spring, *a*, of the jack belonging to that line on the second section. The anvil from this jack is connected to the line spring, *a*, of the jack on the third board, and so on the connection of the line is continued through a jack

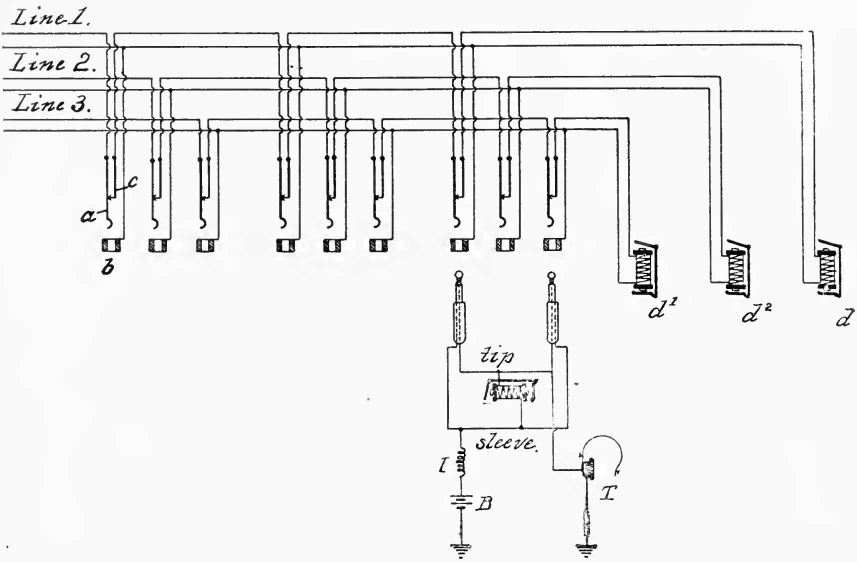


Fig. 174.—Simplified Diagram of Series Multiple Board.

on every section, and finally to the other terminal of the drop, *d*. Lines 2 and 3 pass successively through the sections in a similar manner.

When a subscriber operates his generator, the current passes over the line wire through all of the contacts, *a* and *c*, in series, through the drop-coil, and back over the other side of the line. When an operator inserts a plug into a jack, the spring, *a*, is lifted from contact with the anvil, *c*, by the tip of the plug. The sleeve of the plug makes connection with the test-ring, *b*, and thus the tip and sleeve strands of the plug are connected, respectively, into the metallic circuit of the line, while the circuit through the drop is cut off at the anvil, *c*.

The operator's telephone, *T*, may be then bridged across the cord circuit in order to enable the operator to converse with the

subscriber who has called. Means for connecting the operator's telephone in the circuit in this manner are not shown in Fig. 174, the details of the cord circuit being described later in connection with another figure. This telephone in Fig. 174 is shown connected in a ground branch from the tip side of the cord circuit, in order to better illustrate the principles of testing in this system.

The sleeve strand of each cord circuit is grounded through a battery, *B*, and in order that this ground may not produce serious

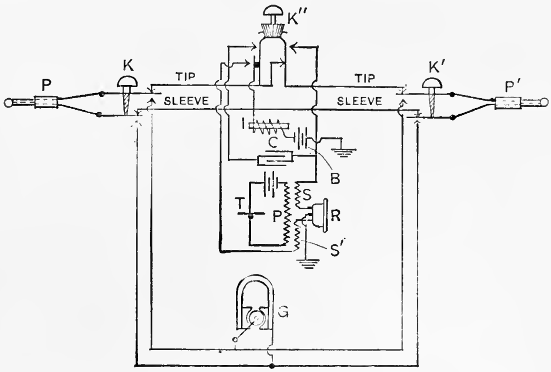


Fig. 175.—Cord Circuit of Series Multiple Board.

effects in unbalancing or crossing the circuit of two connected lines, an impedance or reactance coil, *I*, is placed in this circuit. Whenever any plug is inserted into a jack, one side of the test-battery, *B*, is thrown on to all of the test-rings, *b*, of the line to which that jack belongs. If now an operator at another board desires to make a connection with that line, she touches the tip of her answering plug to the test-ring, *b*, of that line. This will connect the test-ring, *b*, to ground, through her telephone, *T*, and a click will be heard, due to the passage of the current from battery, *B*. The operator will therefore know that that line is busy, and will refrain from making the connection.

In Fig. 174 the three lines have their drops located at section 3. It must be remembered that other lines would pass through jacks on the various sections in a similar manner, but would have their drops located on sections 1 or 2. The operator at any section will, of course, answer calls on lines terminating or having drops on her section only, but she may be required to connect one of these lines to any other line in the exchange by means of the multiple jack.

The details of the cord circuit for this system are shown in

Fig. 175. *K* and *K'* are ringing keys for connecting the generator, *G*, with either of the plugs, *P* or *P'*. The circuit between the plugs is normally maintained continuous, through the tip and sleeve strands, as can be readily seen. When the listening key, *K''*, is depressed, the condenser, *C*, is looped into the tip strand and at the same time the operator's telephone circuit is bridged between the tip and the sleeve strand. The center point of the coil of the operator's receiver, *R*, is grounded, and the secondary coil is split into two parts, *S* and *S'*, one part on each side of the receiver. This arrangement is to prevent the unbalancing of the line by the ground on the receiver coil. The test is made when the key, *K''*, is depressed, the test circuit then being from the the tip of the plug, *P'*, through the tip strand to the right-hand spring of the key and through its anvil, the part *S* of the secondary coil, and one-half of the receiver coil to ground. The condenser, *C*, is for the purpose of preventing disturbances in the line with which the plug, *P*, is connected from giving a false busy test.

The arrangement of circuits here shown is that used in what is termed the series-multiple board, the name series being derived, of course, from the manner in which the line passes through the contact-springs and anvils of the multiple jacks. This system, although once widely used, is subject to grave defects, and is being rapidly replaced by another form of multiple board known as the "bridging" or "branch terminal multiple." In the series-multiple an open circuit may be caused in any one of the jacks by a particle of dust or other foreign insulating matter becoming lodged between the line-spring and its anvil, or by virtue of one of the springs becoming weak and failing to bear upon its anvil. The liability to open circuits, therefore, is very great, especially in large exchanges.

Another serious objection to the series board is that when a plug is inserted into a jack, one side of the line is cut off at the anvil of that jack, but the test side is not cut off, and is continuous through the drop of that line and back to the anvil of the jack which is plugged. This, in a large exchange, means that to one side of the line is attached an open branch, perhaps several hundred feet long and containing the drop-coil. This destroys to a certain extent the balance of the line, and is liable to produce cross-talk.

The branch-terminal system was designed to remedy the defects inherent in the series system, and possesses many advantages over it, chief among which are the facts that when a con-

nection is made with any line the balance of that line is in nowise affected, and that the liability of open contacts in the jacks, which is such a serious defect in the series system, does not exist. The branch-terminal system, moreover, lends itself more readily to the use of self-restoring drops, as will be described later.

In Fig. 176 is represented one type of the branch-terminal system, sometimes called the three-wire system. In this figure

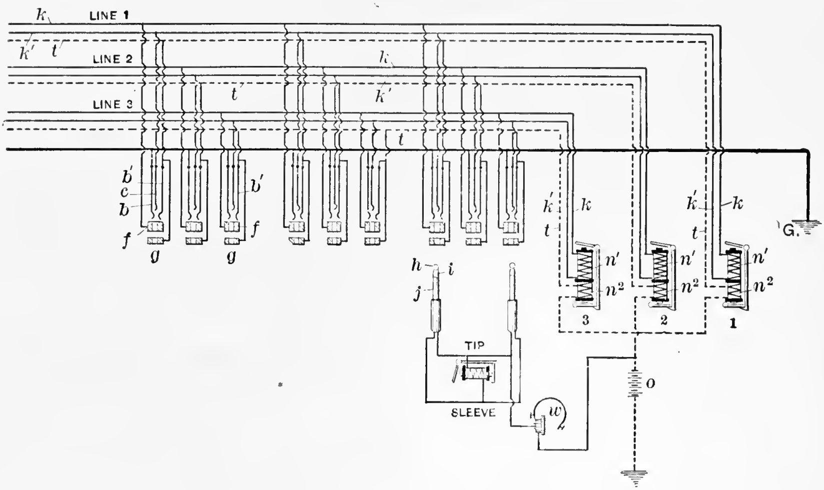


Fig. 176.—Diagram of Branch Terminal Multiple Board.

three distict line circuits are shown passing through three sections of board. The wires, *k* and *k*′, of each line have branch wires leading off to a jack on each board; the branches from wire, *k*, leading to the contact-thimbles, *f*, and the branches from wire, *k*′, leading to the short springs, *c*, in the same jacks. Bridged across the two wires of each line is the line coil, *n*′, of the individual annunciator belonging to that line. This coil is high-wound in order that it may be left permanently bridged across the line without materially affecting the efficiency of the system in talking.

A third wire, *t*, passes through the board in parallel with each line. From this wire branch wires are run to the test-thimble, *g*, and to the spring, *b*′, in each jack belonging to that line. The test wire, *t*, after passing through all of the boards, runs through a low-resistance coil, n^2, on the drop of the line to which that particular test wire belongs, and then passes to ground through a battery, *o*, common to all test wires. These test wires are represented by dotted lines in the figure in order to distinguish

them more readily from the line wires. The remaining spring, *b*, in each jack is permanently connected to a ground wire, *G*, common to all of the jacks.

Each plug in this system is provided with two contacts, *h* and *j*, which form terminals respectively of the sleeve and tip strands of the cord circuit. The tip, *h*, registers with the spring, *c*, when the plug is inserted into the jack (see Fig. 177), and the sleeve, *j*,

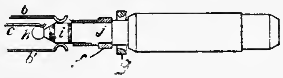


Fig. 177.—Three-Wire Plug and Jack.

registers with thimble, *f*. A conducting ring, *i*, entirely insulated from all other portions of the plug, registers with the springs, *b* and *b'*, in the jack, and connects them together electrically.

Three general results are accomplished by the insertion of a plug into a jack. The tip and sleeve strands of the cord circuit are connected respectively with the sides, *k'* and *k*, of the line, thus continuing the line circuit to the cord circuit. The connecting of springs, *b* and *b'*, by the ring, *i*, completes the circuit of the battery, *o*, through the restoring coil, n^2, of the annunciator, to the ground wire, *G*, and thus allows current from this battery to energize the coil, n^2, and restore the shutter of the annunciator. Lastly, the connecting of springs, *b* and *b'*, by the ring, *i*, connects the test-thimble, *g*, to ground by a short circuit, so that when an operator at any other board touches the test-thimble of that line with the tip of her plug, a signal will be given denoting the line as busy.

In the normal or idle condition of a line, the test-ring, *g*, is electrified to a difference of potential from the earth by the battery, *o*, which finds circuit through the restoring coil, n^2, of the annunciator of that line to all the different test-rings, *g*, belonging to that line at all of the sections of the board. If when the line is in that condition the tip of the test-plug, which is grounded through the operator's receiver and the same battery, be applied to test ring, no current will flow through the receiver because both the tip and the test-ring are at the same potential. Silence will therefore indicate a free line.

When, however, the line has been put into use by the insertion of a plug into the spring-jack thereof, the springs, *b* and *b'*, are connected by the contact-ring, *i*, carried on the plug, whereby all the test-thimbles, *g*, belonging to that line are connected directly to earth through a short circuit, and therefore no

difference of potential exists between them and the earth. Thus, when a test is made on a spring-jack of that line there will be a flow of current through the operator's receiver to ground, and a click will be the result.

Fig. 176 is stripped of all unnecessary detail in order to enable the general underlying principles to be more readily grasped. In Fig. 178 the same system is shown more in detail as to circuits,

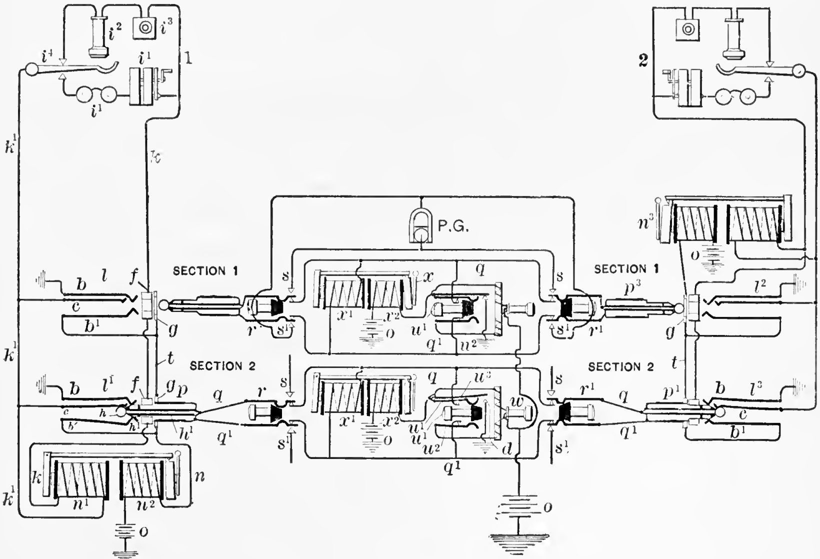


Fig. 178.—Complete Circuits of Branch Terminal Multiple Board.

connections, and apparatus. Fig. 176 will give the reader a better understanding of how the jacks are grouped into sections, and of the relative location of the parts, while Fig. 178 will enable a better study of the circuits.

In this figure two subscribers, 1 and 2, are shown connected by line wires, k and k', with the exchange. Jacks l and l', at sections 1 and 2 of the board, are shown in connection with the line leading from station 1. Jacks l^2 and l^3 are shown connected at the same sections with the line leading from station 2. Across the line leading from station 1 is bridged the line coil, n', of the annunciator, this annunciator being placed at section 2 of the board. The line coil of the annunciator of line 2 is similarly bridged across the two sides of the line, and is placed at section 1 of the board. A little study will show that the circuit of the line wires and the test wires are the same in Figs. 176 and 178,

although represented in an entirely different manner. Like letters correspond to like parts in these two figures.

Two pairs of connecting plugs and their accessory appliances are shown complete, one at each section of the switch-board. The tips of the two plugs of a pair are connected together by one of the conductors, *q*, of the flexible cord, and the sleeves, *j*, are likewise connected by the conductor, *q'*, of the same cord. Included in circuit between the two plugs of a pair are two calling keys, *r* and *r'*, each adapted to disconnect both contact-pieces of one of the plugs from those of the other, and to connect them to the anvils, *s* and *s'*, which form the terminals of the calling generator, *P, G*.

A listening key, *u*, is provided for each cord circuit, having contact points or anvils connected with the conductors, *q* and *q'*, as shown, and having its contact-spring, *u'* and u^2, connected with the terminals of the operator's telephone, *w*. When the plunger of the listening key, *u*, is allowed to rise, the operator's telephone is connected in a bridge across the two sides of the cord circuit, as is shown at section 1. A wire is connected from the middle point of the coil of the operator's telephone receiver to ground through the battery, *o*, so that when a test is made of any line, as was described above, a circuit will be completed from the contact-thimble, *g*, of the jack through the tip strand, *q*, of the cord circuit, and thence through one-half of the operator's receiver coil to the ground. As this wire leads from the center part of the operator's receiver coil, it may be left connected permanently, as it does not destroy the balance of the line.

A clearing-out annunciator, *x*, similar in construction to the line annunciator, has its high-resistance coil, *x'*, bridged permanently across the two sides of each cord circuit. The restoring coil, x^2, is connected in a normally open local circuit, including the battery, *o*, and terminating in the ground on one side, and in a spring, u^3, on the other. This spring, u^3, is arranged in conjunction with the listening key in such a manner that when the key is raised the spring will make contact with a grounded anvil, *d*. Thus, whenever the operator listens in on any cord circuit she at the same time restores the clearing-out drop if it happens to be down.

In order to give the reader a clearer understanding of the system so far described, it will be well to follow the operation in connecting one subscriber with another. Suppose Subscriber 1 desires connection with Subscriber 2. He operates his generator, *i*, and the current therefrom passes over the line wires, *k k'*, and

through the coil, n', of the line annunciator, n, at section 2 of the board. The operator, noticing this signal, inserts plug, p, into jack, l'. This completes the circuit from ground, through battery, o, coil, n^2, of the line annunciator, thence to spring, b', through the ring, i, on the plug to spring, b, and to ground. The front armature of the annunciator is therefore attracted and the drop restored.

The operator then connects her telephone across the cord circuit by raising the key, u, and communicates with Subscriber No. 1, in order to ascertain his wishes. Having found that he desires a connection with Subscriber No. 2, she takes up plug, p', of the same pair and tests to find out whether line No. 2 is connected to at some other board. If it is busy a current will pass from battery, o, through one-half of the coil of her receiver, and one part of the secondary to the spring, u', in the listening key. From this spring it passes to the tip strand, q, of the cord circuit, and to the tip, h, of the testing plug. As the test-thimble to which the plug is applied is grounded by the insertion of a plug at another board, the current will pass through it to ground. This will produce a click, which will indicate to her that the line is busy, and she will not complete the connection called for. If, however, she finds the line to be free she thrusts the plug entirely into the jack, in which position it is shown in the figure, and depresses the key, r', in order to throw current from generator P, G, upon the line of Subscriber No. 2.

The two subscribers are now connected for conversation. When either rings off the current passes through the coil, x', bridged across the cord circuit, and actuates the clearing-out drop. The operator, noticing this, again listens in, by raising the key, u, in order to find out whether they are through talking, or whether one of them desires another connection. The act of listening in closes spring, u^3, against anvil, d, and thus restores the shutter of the clearing-out drop. If the subscribers have finished talking, the plugs are removed and placed in their normal resting place.

If, while Subscribers 1 and 2 were connected together at section 2, as above described, someone at section 1 had desired connection with, say, line No. 2, the operator at section 1, in applying the tip of her plug, p^3, to the test-thimble, g, as shown, would receive a click in her receiver for the reason, as pointed out above, that contact, g, is connected to the ground by a short circuit by the plug inserted in jack, l^3. No difference of potential would, therefore, exist between thimble, g, and the ground, and hence a

current from the battery, *o*, would pass through the telephone of the operator making the test.

Success in practical telephone working can be attained only by the greatest attention to matters of detail. Nowhere is this fact better illustrated than in the design of the various parts which go to make up a multiple board. In the construction of large boards

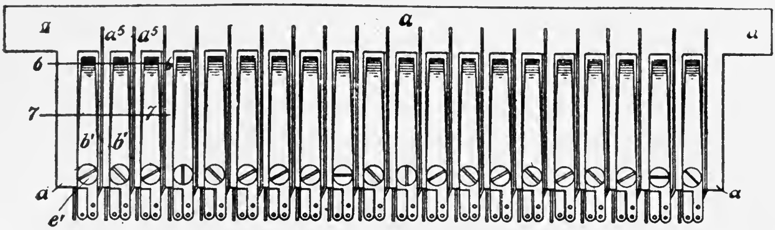


Fig. 179.—Plan View of Multiple Jack-Strip.

of this type, the possible capacity of the board is limited by the number of spring-jacks that can be placed within the reach of a single operator. It is evident, therefore, that space must be economized to the last degree, and yet the jacks must be substantial, in order to resist the wear and tear of years of service; must be made easily removable so as to be accessible for repairs; must perform their electrical functions with absolute certainty, and at the same time be so arranged as to facilitate the orderly

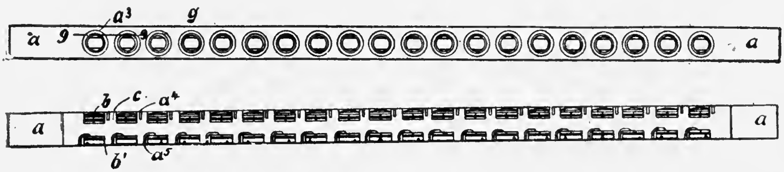


Fig. 180.—Front and Rear View of Multiple Jack-Strip.

and systematic connection of the wires leading from the line cables.

Moreover, when we consider that a multiple board with a capacity of 5000 subscribers will have in the neighborhood of 130,000 spring-jacks, we can easily realize that the cost of producing these jacks must be seriously considered. It is well to state here, however, that any economy in the construction of a switchboard that will tend to decrease its durability and reliability of action is poor economy indeed.

As an illustration of modern spring-jack construction, we will consider the spring-jacks used in the branch-terminal multiple

board just described. It has become common practice to mount the jacks in strips of twenty, and to so arrange each strip that it may be removed from the board by the removal of two screws, which bind it firmly to the framework. Figs. 179 to 182, inclusive, show the details of the construction of one of these jack-strips.

The hard-rubber strip, *a*, forms the framework for each strip of twenty jacks. The projections at its ends provide for attach-

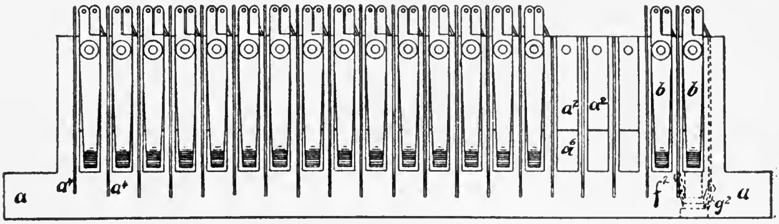


Fig. 181.—Bottom View of Multiple Jack-Strip.

ment to the switch-board. In this strip are milled, on its upper side, the transverse grooves, a^1 a^1, and on its lower side similar grooves, a^2 a^2; these being best seen in the right-hand portion of Fig. 182.

Perforations are drilled from the front of the strip, one perforation to each pair of grooves, having its axis centrally located

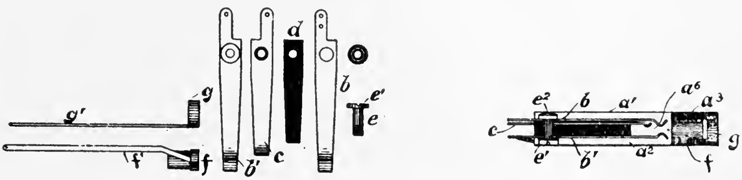


Fig. 182.—Details of Jack Parts.

and parallel with respect to the grooves. A small portion of the hard rubber is removed from between the grooves so as to leave a rectangular opening, a^6, shown in Figs. 181 and 182, through the strip connecting the two grooves at those ends which are nearer the front of the jack. In the grooves, a^1, upon the upper surface of the rubber strip are mounted springs, *b* and *c*. The spring, *b*, is the longer of the two, so that its curved extremity is presented close to the end of the perforation through the front portion of the strip, *a*. The springs are insulated from each other by a strip or tongue, *d*, of hard rubber, thin and flexible enough not to impede the flection of the two springs. In the

under groove, a^2, is mounted another spring, b^1, similar to spring, b, and of equal length.

The three springs, b, c, and b^1, are firmly secured to the strip, a, by a bolt, e, passing through them and the body of strip, a. The bolt is insulated from the springs, b^1 and c, by rubber washers and bushings. In the perforations, a^3, in front of the strip, are inserted short tubes, f, of brass. Each tube or thimble, f, is provided with a shoulder, which bears against a corresponding ledge in the perforation, a^2, so as to prevent the tube from being thrust backward toward the rear of the jack by the insertion of the operators' plugs. The thimble, f, is provided with an extension, f^1, to afford electrical connection with it from the rear of

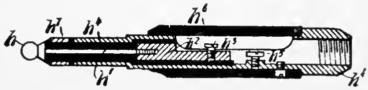


Fig. 183.—Details of Plug.

the jack. This strip, f^1, extends through an oblique duct, f^2—shown in dotted lines in Fig. 181—and thence through a transverse slot or saw-cut, a^4, to the rear of the strip.

In front of the thimbles, f, in the perforations, a^3, are placed the test-rings, very short tubes of brass, g. These are forced into place against other ledges in the perforation. The ring, g, is also provided with an extension, g^1, projecting to the rear of the strip of spring-jacks. These extensions, g^1, are of wire and pass through another duct, g^2, in the front portion of the strip, a, into a saw-cut, a^5, thence to the rear of the strip, where they are connected with the spring, b.

The springs in these jacks are of hard German silver, which has been found the most desirable material for this and similar purposes.

The detail of one of the plugs used with these jacks is shown in Fig. 183. The tip, h, of brass is secured by the rod, h^1, to the block, h^2, also of brass. Insulated from the tip portion by a rubber bushing is the sleeve contact, h^4, of the plug, which projects rearwardly and forms the main body of the plug. Over this portion is slipped a shell, h^6, of hard rubber or fiber, which forms a handle for the plug. Between the tip and sleeve, and insulated from each, is the ring, h^7, which, as was described before, is for short-circuiting the springs, b and b^1, when the plug is inserted in the jack.

Screw connectors, h^3 and h^5, form convenient terminals for

attaching the strands of the cord to the tip and sleeve, respectively, of the plug. These connectors are always readily accessible for inspection or repair by the removal of the sleeve, h^6.

This brings us to the subject of flexible cords for switch-board use. The matter seems at first thought to be a simple one, but much thought and time have been spent in perfecting this branch of the equipment. Even at this late day the best cord is not good enough. As near a perfect cord as has up to the present time been made is constructed as follows: each conductor in the cord is composed of strands of tinsel and a few fine copper wires, to add strength and conductivity. Around each of these conductors are wrapped tightly, in opposite directions, two layers of floss silk. These should be wrappings and not braids, as a wrapping serves to keep any broken ends of the tinsel or wire down in the bunch better than a braid. Around these wrappings of silk is a braid of linen, which adds strength to the conductor. If the cord be for a metallic circuit, the two conductors thus formed are then wrapped with two more layers of floss silk, and the whole is then encased in a strong spiral wrapping of hard spring brass wire. The wire in this spiral is stiff enough to retain its shape, but the spiral as a whole is so flexible as to allow free bending of the cord. An outer covering of polished cotton is tightly braided over the spiral, and after the ends are tightly anchored to prevent the conductors sliding back and forth in the spiral, the cord is complete. An extra layer of outside linen braid is often put on the cord for a distance of about one foot back of the plug, to prevent the sharp bending or kinking of the cord by the operator in inserting the plugs into the jacks.

For handling very large exchanges Mr. Milo G. Kellogg of Chicago has invented a number of divided multiple-board systems, some of which will probably prove important factors in the telephone industry of the immediate future. In these he divides the lines into four classes and the switch-boards into corresponding divisions, one division for each class of lines. Each line has four polarized drops and four answering jacks, one drop and jack being located on each division of the boards. In addition to this each line has a multiple jack on each section of one of the divisions, the arrangement being the same in this respect as in the ordinary multiple-board. Two of the polarized drops are of opposite polarity and are connected in series between one side of the line and ground. The other two are also of opposite polarity and are connected in series between the other side of the line and ground. By sending a current of one polarity or the

other over one or the other of the line wires and ground, a subscriber may thus signal any division of the exchange.

In operation, if a subscriber in class A desires to call one in class D he sends, for instance, a negative current over the test side of the line, which operates his drop at division D of the exchange. As the called subscriber belongs to the D class he will have a multiple jack upon each section of the D division of boards, and the operator will answer the call from the A line, by inserting a plug in the answering jack,—which is always on the same section as the drop,—and complete the connection by

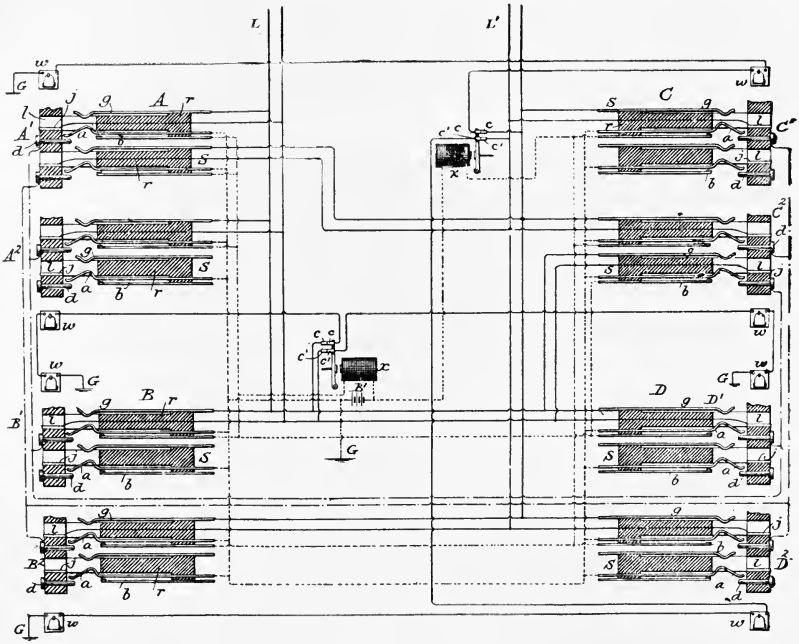


Fig. 184.—Kellogg Divided Multiple Switch-Board.

inserting the other plug of the pair in one of the multiple jacks of the D subscriber called for. The calling of any division of the exchange is done by an arrangement of push-buttons at the subscriber's station, the subscriber always pressing the button bearing the letter of the class to which the subscriber called belongs.

In Fig. 184 is shown diagrammatically the circuits of one of the Kellogg divided board systems. The four divisions of the board are represented by A, B, C, and D; A^1 A^2, B^1 B^2, etc., representing the various sections of board in each division.

Each jack, S, is composed of a tip contact, g, a sleeve contact, j, a test contact, d, and two auxiliary contacts, a and b, adapted to be pressed into engagement with each other and with the test contact by an insulated portion carried on the connecting plugs.

L and L' are two subscribers' lines. Line L is an A line, and therefore has a jack on each section of division A, and one jack on one section only of each of the other divisions. Line L' belongs to class C, and therefore has a jack on each section of the C division and on one section of each of the other divisions.

Line cut-off relays, x x, are provided, one for each line. Each of these is included in a local circuit containing the common battery, B', the ground, and the springs, a and b, of each jack belonging to its particular line. These relays when operated cut off both taps to ground, containing the line-drops, w, of which there are four for each line. The insertion of a plug into a jack, therefore, by pressing together contacts, a and b, operates the relay, x, to cut off all the drops from the line. It also connects the test contact, d, with the ground at G through the spring a; and as all the test contacts, d, of the jacks on one line are permanently connected together, all are grounded. This grounding of all test contacts of the jacks belonging to a busy line is to enable an operator to determine the condition of the line. The tip side of her cord circuit is while making the test grounded through an impedance coil and battery. If the line tested is busy, she obtains a click due to the closed circuit from the tip of her plug to ground through the test contact and spring, a. If the line is free the test contact is not grounded, the circuit remains open, and no click is obtained.

The advantage claimed for this division of multiple-boards is the enormous saving of multiple jacks. The limit to the number of subscribers in a single multiple board is found to be about 6000, a greater number rendering the boards so cumbersome that an operator cannot reach all of the multiple jacks on her section. By thus dividing the exchange into four divisions it becomes possible to place as many as 24,000 subscribers in a single exchange.

CHAPTER XX.

TRANSFER SYSTEMS.

No person of intelligence can visit one of the large exchanges of the Bell Company, equipped with a modern multiple switch-board, without being deeply impressed by the magnificence of the equipment, the perfection of the system in its entirety and in its minutest detail. If he is conversant with telephone matters, he must also be impressed by the fact that while the multiple switch-board gives the subscriber what he needs,—quick reliable service,—it gives it only at a great cost to the operating company. There is no question but that at the present stage of telephonic development the multiple-board systems represent the highest type of central-office equipment, and while one form or another of them are in use in nearly all the really large exchanges the world over, there are a few notable exceptions. The success of some of these, coupled with the enormous expense necessarily entailed in the installation of large multiple boards, leads the writer to believe that the coming system, while it may in some degree embody the plan of multiple jacks, will depend for its action on other ideas already developed to a considerable extent.

In the multiple switch-board the cost of installation increases approximately as the square of the number of the subscribers. When a new section containing, say, 200 spring-jacks, annunciators, and other apparatus, is added to an exchange, the increase does not end there. Two hundred multiple jacks must be added also to each of the sections already existing in the exchange. This is clearly an objection which increases in seriousness as the exchange grows. A multiple board, of the type so far considered, having a capacity for 6000 lines, would probably be divided into 30 sections of 200 lines each. On each section would be placed 6000 multiple jacks, plus the 200 answering jacks belonging to the particular 200 lines whose annunciators were located at that section. This would make a total of 6200 spring-jacks on each section, or 186,000 in all. The first cost is, therefore, large; increasing the board is excessively expensive, and cost of maintenance is necessarily heavy.

The enormous multiplying of jacks in the multiple system is for one purpose—to enable each operator to have within her

reach a terminal of every line in the exchange, to the end that she may be able herself to complete any connection called for over any one of the lines under her immediate supervision: that is, that she may be able to answer any call arising at her section, and, without requiring the aid of any other operator, make the connection called for. In other words, in a 6000 exchange, 186,000 spring-jacks would be used, instead of only 6000, in order to accomplish this result.

Clearly, if multiple jacks are not used, two operators or more will have to be instrumental in making a connection between two subscribers whose lines terminate on different portions of the board. It would seem at first thought that this would be a considerable disadvantage, and would result in a slower system. On further consideration, however, why should it be more of a disadvantage to divide the labor of manipulating a switchboard between several operators, than it is to apportion the labor of making a pair of shoes or any other manufactured article among a large number of operators, as is now done in all large factories?

The loss of time required by one operator having to repeat an order to another, or, as is the case in some systems, of the subscriber having to repeat his own order, is at least partially compensated for by the gain in simplicity over the multiple system.

Systems depending for their operation on the transfer of a connection from one portion of a board to another are termed transfer systems, and one of the most successful of these is the so-called "express system" of Messrs. Sabin & Hampton of San Francisco. This system has been used for several years in San Francisco, and has, according to reports, demonstrated its capability of handling with success an exchange having over 6000 subscribers.

The system is so radically different from anything so far described that its consideration in detail should be a matter of much interest. One striking feature in it is that no magneto-generators are used at the subscriber's station, and when it is considered that approximately one-third of the cost of a complete telephone set of the ordinary type is in the magneto, it will be seen that this is a saving of considerable moment. The doing away of the magneto, however, is not an essential feature of the express system, but is one of the advantages incident to its use.

Briefly stated, the underlying ideas of the express system are as follows: The boards are divided into two classes, termed for convenience "A" and "B." Similarly, the operators at the respective boards are termed "A" operators and "B" operators.

There is but one line jack for each line in the exchange, and these are divided into groups of one hundred each and are placed only at the "B" board. At the "A" boards, which are entirely removed from the "B" boards (they may even be in another exchange), are placed plugs which form the terminals of other trunk lines leading *from* the various "B" boards; and also jacks forming the terminals of other trunk lines leading *to* the "B" boards.

The former trunk lines—that is, those terminating in plugs at the "A" boards—also terminate in plugs at the "B" boards. These are termed "A" trunk lines. The latter trunks—that is, those terminating in jacks on the "A" boards—terminate in plugs on the "B" boards, and are termed "B" trunk lines. When a call is received it attracts the attention of one of the "B" operators by displaying an annunciator in the ordinary manner. The "B" operator at whose board the call is received pays no further attention to it than to insert one of the plugs of an "A" trunk into the jack of that line, thus transferring the call to an "A" operator, who answers it with a listening key in the ordinary manner. No means whatever are provided for a "B" operator to listen in on a subscriber's circuit, this duty being confined solely to the "A" operators.

The "A" operator, having learned that the subscriber calling desires to be connected with a certain other subscriber, conveys this information, by means of a special order wire, to the "B" operator at whose board the called-for subscriber's line terminates. The "B" operator then tells the "A" operator what "B" trunk line to use, and the "A" operator then inserts the plug of the "A" trunk line used into the jack of the "B" trunk line thus designated. This brings the connection as far as the board of the second "B" operator; that is, the "B" operator at whose board the called-for subscriber's line terminates. This operator, in order to complete the connection, simply inserts the plug of the "B" trunk used into the jack of the called-for subscriber's line, and presses a ringing key in order to call that subscriber.

It will be seen that the connection has really been handled by three different operators, but that the first of these operators does no more than to insert a plug into a jack, giving the matter no further attention.

All signaling between the subscribers and the operators and between the various operators, whether it be for establishing or clearing out a connection, is entirely automatic, and therefore not dependent upon the volition of the parties concerned.

Fig. 185 shows the arrangement of the circuits at the subscriber's station, and also the arrangement of the spring-jacks and annunciators on the "B" boards. One side of the line wire at the subscriber's station is normally grounded through the polarized ringer, *R*. This means that calling a subscriber from the central office must be accomplished over one limb of the line

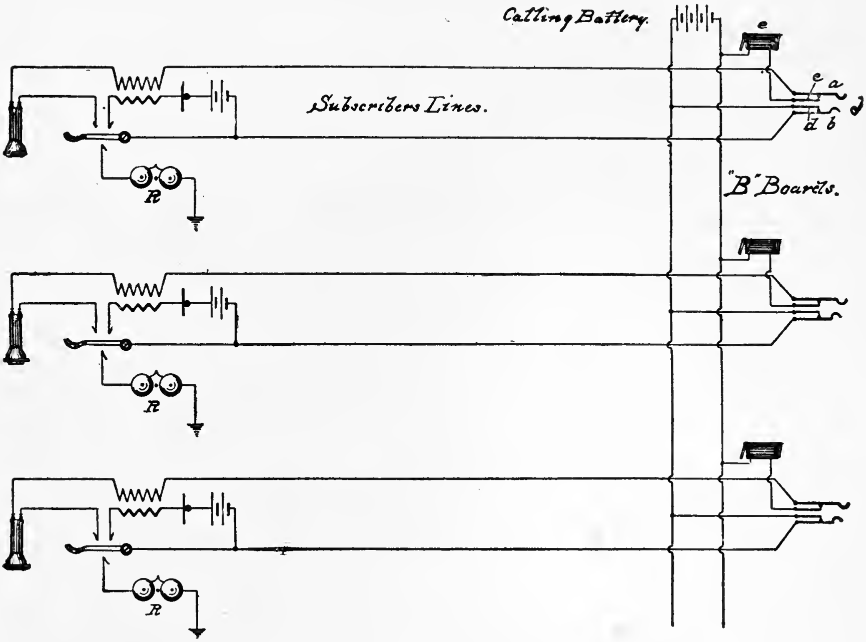


Fig. 185.—Subscribers' Circuits—Express System.

wire and ground, instead of over a metallic circuit, as in case of talking and other signaling in this system. The other circuits and apparatus at the subscriber's station are of the ordinary arrangement and type, the only difference being that the magneto-generator is omitted entirely. The line wires of each subscriber terminate in two springs, *a* and *b*, of their spring-jack, *J*. These springs normally rest on two anvils, *c* and *d*, one of which connects through an annunciator, *e*, with a heavy wire leading to one pole of the calling battery, and the other of which leads to a similar wire connecting with the other pole of this battery.

This annunciator, *e*, has a shutter which is simply lifted by the attraction of the armature, and again dropped into its normal position when the armature is released. It is, therefore, the simplest type of self-restoring drop. The circuit of the call-bat-

tery is normally open only at the subscriber's station. It is automatically closed through the receiver and secondary winding of the induction coil at the subscriber's station whenever the subscriber removes his receiver from its hook. This allows enough current from the calling battery to pass through the drop, *e*, to raise its shutter, and thus attract the attention of the "B" operator at that board.

The shutter remains raised until the operator inserts the plug of one of the "A" trunk lines in order to transfer the call to the "A" operator. The insertion of this plug, however, lifts the springs, *a* and *b*, from the anvils, *c* and *d*, thus cutting off the battery and allowing the shutter of the annunciator, *e*, to drop to its normal position, and the "B" operator therefore pays no more attention to it.

A single battery is made to serve for actuating the signals of every line in the exchange, no matter how great their number may be. Storage cells are used for this purpose, ten cells being connected in series so as to give a pressure of about twenty volts. It is said that the average flow of current from this battery is about one and one-half ampere, and never exceeds two amperes, in the San Francisco exchange of approximately 6000 subscribers. It will be thus seen that the cost of maintenance of these batteries is trifling.

Another good feature of this arrangement is that, should a "B" operator by mistake withdraw a plug from a jack before a subscriber has finished talking,—that is, before he has hung up his receiver,—she will be at once notified of her mistake by the display of a signal belonging to that line.

In Fig. 186 is shown a simplified diagram of the express system. At the bottom and top of this figure are shown the subscribers' lines, leading in each case from the subscriber's telephone apparatus to the drop and jack at the central office. This part of the apparatus is the same as that shown in Fig. 185, but in this figure the details of the local circuit at the subscribers' stations have been omitted for the sake of clearness.

The jacks and drops belonging to these lines are, as has already been stated, stationed at the "B" boards of the exchange. The subscriber's indicator battery is represented at *S I B* and the indicators at *I*. Leading from the section of the "B" board shown at the top of the figure is a trunk line leading to a plug on the second section on the "A" boards. It will be noticed that this trunk line terminates in a plug at each end, and is termed the "A" trunk. An intermediate jack and plug are shown in the

circuit on this "A" trunk, but these at present need not be considered. Suffice it to say that the plug at the "B" board is connected by a metallic circuit to the plug at the second section of the "A" board. Leading from a certain jack on the second section of the "A" board is a trunk line extending to a plug on another section of the "B" boards. This is termed a "B"

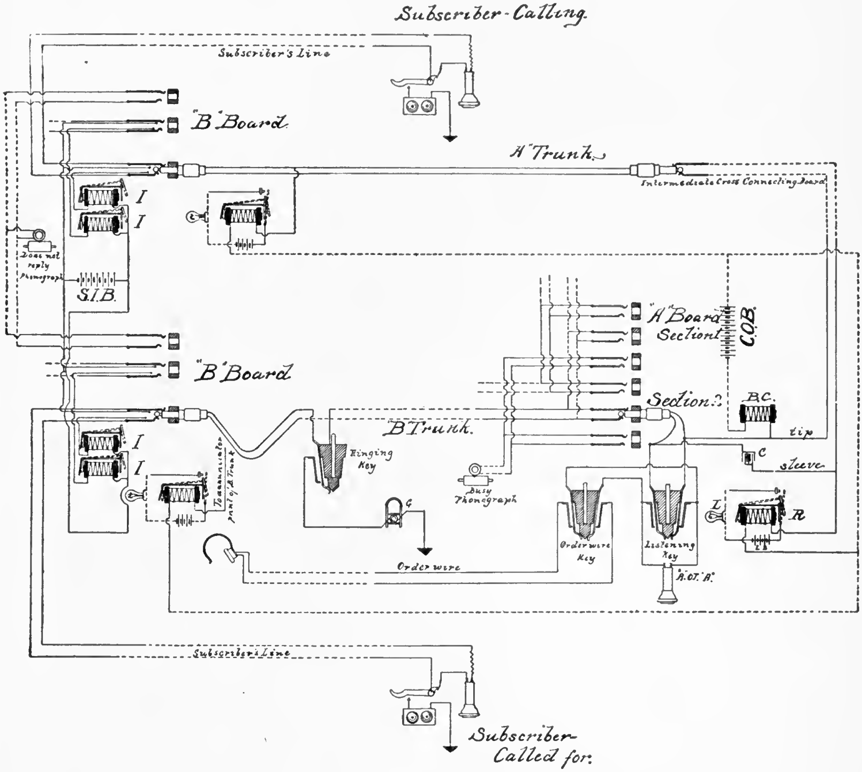


Fig. 186.—Simplified Diagram—Express System.

trunk. Only one "A" trunk and one "B" trunk are shown, but it must be remembered that a number of "A" trunks lead from each of the "B" boards to the "A" boards, and that from the "A" boards a number of "B" trunks lead back to each of the "B" boards.

When a subscriber, as for instance the one shown at the top of the figure, removes his receiver from its hook, his indicator, *I*, is displaced automatically, and the operator at the particular "B" board at which this indicator is located extends the circuit of his line to one of the "A" boards over an "A" trunk. This

she does by inserting the plug of an "A" trunk into the jack of the calling subscriber. The operator at the "A" board, having learned the desire of the calling subscriber, extends the circuit to that subscriber's line by means of the "B" trunk, still further on to the particular "B" board at which the jack of the called subscriber is placed. This the "A" operator does by inserting the plug of the "A" trunk used into the jack of a "B" trunk at her board. The "B" operator at whose board the calling subscriber's jack is placed then completes the connection between the two subscribers by inserting the plug of the "B" trunk used into the jack of the calling subscriber's line. The two subscribers' lines are shown connected in Fig. 186 by the process and over the circuits just described.

In order to facilitate matters it is evidently necessary that a most complete and elaborate set of signals must be provided between operators. The first in this series of signaling operations is to notify the "A" operator that her attention is desired on a certain "A" trunk. This must always occur just after the "B" operator has inserted one of the "A" trunk plugs into the jack of the calling subscriber's line. It will be noticed in Fig. 186 that the relay, *R*, operating signal lamp, *L*, is bridged across the tip and sleeve strands of the "A" trunk circuit, and this bridge may be traced from the tip strand through the balance coil, *B C*, thence through the clearing-out indicator battery, *C O B*, to the battery wire, thence through the coil of the relay at the "A" board, and thence to the sleeve strand of the "A" trunk. Remembering that the calling subscriber at the top of the figure has removed his receiver from its hook, then the insertion of the plug of the "A" trunk will restore the line drop, *I*, and at the same time will close the circuit from the clearing-out indicator battery, *C O B*, and the relay, *R*, through the subscriber's line and telephone instrument. This will operate the relay and cause it to close the circuit of the signal lamp, *L*, thus calling the attention of the "A" operator to the fact that an unanswered call is upon the trunk line to which that lamp belongs.

The apparatus of the "A" operator is shown more clearly in Fig. 187. The sleeve and tip strands of the "A" trunk are shown at the extreme left of this figure. When the armature of the relay, *R*, is attracted, as described above, the circuit from the local battery and white lamp is completed at the point, *b*, of the relay. It will be noticed that this local circuit extends through two of the springs, *e* and *f*, normally closed, on the listening key of the "A" operator, and also through a pair of contacts, *l* and *c*,

held closed by the weight of the plug of the "A" trunk in its socket. The white lamp will therefore remain lighted until one of the following three things happens: until the operator listens in, which causes the local circuit to break at the listening key; or until she removes the plug of that trunk line from its socket, which would break the local circuit at the point, *c;* or until the calling subscriber hangs up his receiver, which would cause the relay to let go of its armature, and thus break the circuit at point, *b.* The white lamp remains lighted, therefore, as long as the call on its "A" trunk is unattended to.

The first act of the "A" operator on seeing this light is to throw her lever corresponding to that light into its horizontal position, thus connecting her telephone to the terminals of the "A" trunk in the usual manner. This enables the "A" operator to communicate with the calling subscriber in the ordinary manner. It should be noted that these keys on the "A" operator's boards are the only means afforded to any operators for communicating with subscribers. The operation of this key breaks the circuit of the white lamp at the points, *e f.* As soon as the listening key is thrown again into its normal position the white lamp is again lighted, thus calling the operator's attention to the plug to be used in making the connection.

This precaution is a wise one, for before making the next move in the connection, the "A" operator must communicate with the "B" operator at whose board the called-for subscriber's line terminates. The "A" operator does this by depressing her order-wire key, shown in Fig. 186, but omitted from Fig. 187, which act connects the "A" operator's telephone directly with the telephone set of the outgoing "B" operator. The "A" operator then tells the "B" operator the number of the line with which connection is desired, and the "B" operator in return tells the "A" operator the number of the trunk line she is to use in making the connection.

Herein lies one of the greatest defects of the system. That is, the necessary waiting by the "A" operator for the reply of the "B" operator. This is a loss of time on the part of the "A" operator, for it often occurs that the "B" operator may have several other connections under way which she could not well leave in order to reply to the "A" operator by designating the number of "B" trunk to be used.

It will be noticed that the trunk jacks of the "B" trunks are in reality arranged on the plan of the multiple board. This is for the purpose of placing within the reach of every "A" opera-

tor a jack belonging to every "B" trunk line. No test system, however, is required on these jacks, as an "A" operator always first learns from an outgoing "B" operator which "B" trunk to use, and of course a "B" operator would never designate any trunk which was already in use, or "busy."

It would seem that a "busy" test, or preferably a visual "busy" signal for the multiple jacks on the "A" boards could be used

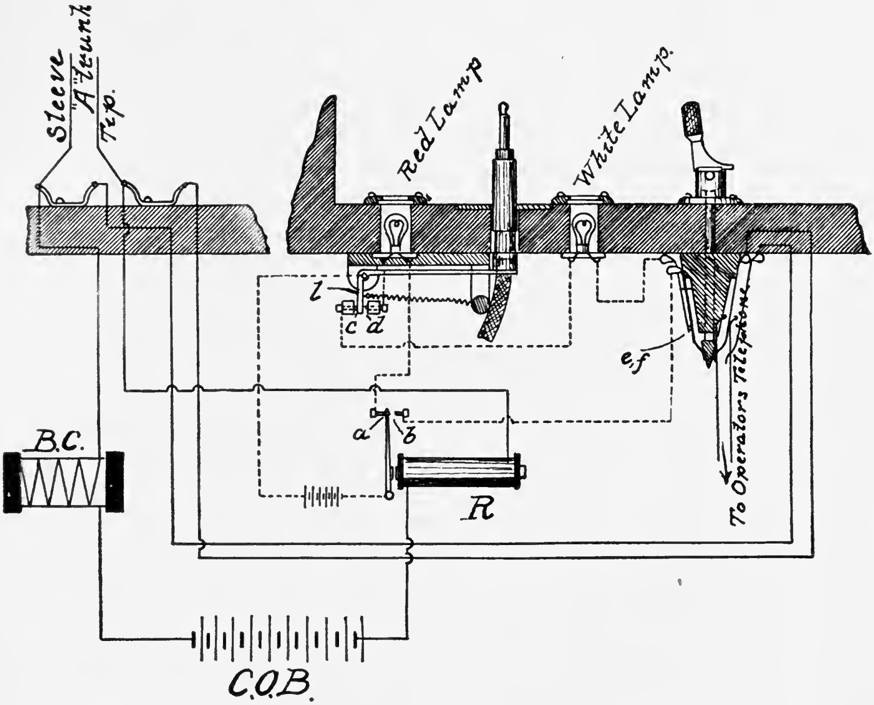


Fig. 187.—Table of "A" Board.

with advantage. This would enable the "A" operator to at once select an idle "B" trunk and at the same time inform the proper "B" operator of the connection to be made and the trunk line plug to use in making it. For instance, the "A" operator could simply say: "1504 on 10," meaning by the first number the number of the subscriber called for, and by the second number the trunk line to be used.

We have now carried the connection, or extended the circuit of the calling subscriber's line, as far as the trunk line plug at the outgoing "B" board. The outgoing "B" operator then completes the connection by inserting this plug into the jack of the

called subscriber. The "B" operator then depresses her ringing key, shown in a simplified form in Fig. 186, which sends calling current from the generator, *G*, over the sleeve strand of the plug cord, thence to line and to ground through the polarized call-bell at the subscriber's station.

The next feature to consider is that of the automatic clearing-out signals. As the connection between the two subscribers is made by three operators, it is evident that three distinct clearing-out signals should be given, one at each of the boards of the operators who help establish the connection. Turning again to Fig. 187, it will be seen that the raising of the "A" trunk plug from its socket changed the circuit of the local battery from the white lamp to the red lamp, by moving the selecting lever, *l*, from the point, *c*, to the point, *d*. Remembering now that as long as the calling subscriber's receiver is off its hook, the circuit from the clearing indicator battery is closed through the relay, *R*, at the "A" board, thus attracting its armature. As soon, therefore, as the calling subscriber finishes his conversation, he hangs up his receiver, and thereby breaks the circuit through the relay at the "A" board, thus closing the circuit through the red lamp. This lamp will therefore be lighted as a notification to the "A" operator that disconnection on that trunk is desired. The replacing of the plug in its socket opens the circuit of the red lamp at the point, *d*, thus extinguishing the lamp. This apparatus at the "A" board is very ingenious, and deserves special attention. It should be noticed that should an operator by mistake remove one of the "A" plugs, and replace it in its socket before the subscriber connected had hung up his receiver, the white lamp would be relighted, thus calling the attention of the operator to the error.

The clearing-out signal is given to the incoming "B" operator in much the same way as that on the "A" board, the clearing indicator, or relay, on the "A" trunk of the "B" board being wired in multiple with the relay on the "A" board.

The clearing-out signal on the outgoing "B" board is accomplished by much more complicated means, and will be explained by reference to Fig. 188. In this figure the ringing key, *f*, is shown in more detail than in Fig. 186. The "B" trunk line jack on the "A" board is represented by *a*. In the normal position of the key the two strands of the "B" trunk are connected to the tip and sleeve of the corresponding plug on the outgoing "B" board. When, however, the key is depressed, the sleeve strand of the cord is connected with the calling generator, the other terminal of

which is grounded. When the operator depresses this ringing key, a secondary pair of contacts, $i\ i^1$, are closed, thus actuating the lower magnet, l, of the compound relay, and causing it to attract its armature, l^1. When the operator allows the key, f, to rise, the armature, l, falls back, but is caught by the hook, m^1, of the upper coil, m, of the relay. The hook, m^1, and the tip of the armature

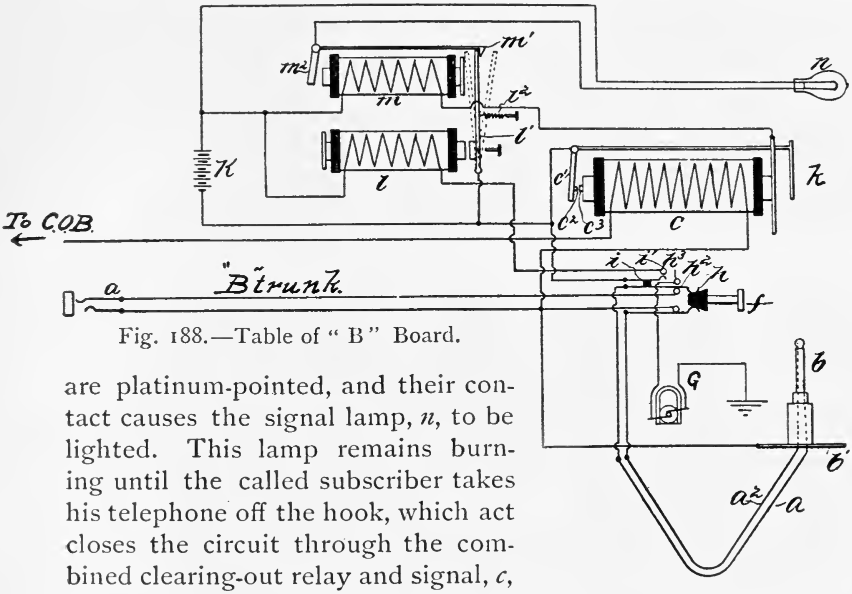


Fig. 188.—Table of "B" Board.

are platinum-pointed, and their contact causes the signal lamp, n, to be lighted. This lamp remains burning until the called subscriber takes his telephone off the hook, which act closes the circuit through the combined clearing-out relay and signal, c, in exactly the same manner as the relays on the incoming "A" trunk line were operated. The operation of this relay therefore closes a circuit at the points, $c^2\ c^3$, through the upper magnet, m, causing it to raise the hook, m^1, and allow the armature, l^1, to drop back. This extinguishes the lamp, n, and shows the operator that the subscriber has responded. The armature, c^1, of the relay, c, remains attracted until the called subscriber hangs up his receiver, which de-energizes the magnet, c, and allows the signal carried by the armature to resume its normal position. This is the clearing-out signal for the outgoing "B" operator, and she accordingly pulls out the plug.

To review the action of the indicators at the outgoing "B" board, the releasing of the key for transmitting a calling signal to the subscriber lights the lamp, n, and shows the operator that this part of her work has been attended to. The response of the subscriber is indicated by the going out of the lamp, and by the raising of the signal, k. The clearing-out signal is given by the lowering of the signal, k.

We have now traced through the operation of all the signals between the subscribers and the operators, and between the operators themselves, which were necessary to establish a connection between two subscribers; and also the subsequent signals between the subscribers and the operators, indicating that a disconnection is desired. The striking feature of all this elaborate system of signaling is that each signal is automatically given without the volition of the operator or subscriber, inasmuch as it is brought about by some action necessary in the actual connection or disconnection.

In order to reduce the work of the operators to the last degree, two phonographs are placed in connection with the exchange, one of which is constantly and politely repeating the sentence, "Busy. Please call again," while the other repeats with equal regularity, "Subscriber called for does not reply." Each of these phonographs speaks to a transmitter arranged in connection with an induction coil and battery in the ordinary manner. The terminals of the secondary of the induction coil of the "busy" phonograph terminate in a jack on each section of the "A" boards. In like manner the "does not reply" phonograph is connected with a jack on each section of the "B" boards. When, therefore, an "A" operator learns that a line called for is busy, she inserts the plug of the "A" trunk to which the calling subscriber is connected into the phonograph jack, and the familiar but disappointing message, "Busy. Please call again," is automatically conveyed to the calling subscriber.

In a similar manner the outgoing "B" operator may inform the calling subscriber that the subscriber called for does not respond. The use of the phonograph for this purpose may seem at first thought to be carrying the labor-saving idea to an extreme, but it enables an operator to attend to another subscriber while she is telling the first subscriber that his line is busy or that his party does not respond. It moreover insures that the wrath of the calling party will produce no evil effects on the nerves of the operator, which at busy times is no unimportant consideration.

The writer is indebted to an able article by Mr. George P. Low, in the *Electrical Journal*, for much information concerning this very interesting exchange system.

Fig. 189 is a schematic representation of the system used in the larger exchanges of the Western Telephone Construction Company of Chicago. This system has proved very successful in practice for exchanges up to fifteen hundred subscribers, although with a larger number certain difficulties are met in

the disposal of the transfer plugs. In this figure 1, 2, 3, 4, etc., represent different sections of the board, each section having one hundred combined drops and jacks of the type shown in Figs. 158 and 159 together with a complete operator's equipment. One answering plug, *A*, together with one calling plug, *B*, is shown at each section. These are connected together in pairs through clearing-out drops, *O*, by ordinary flexible cords which contain the

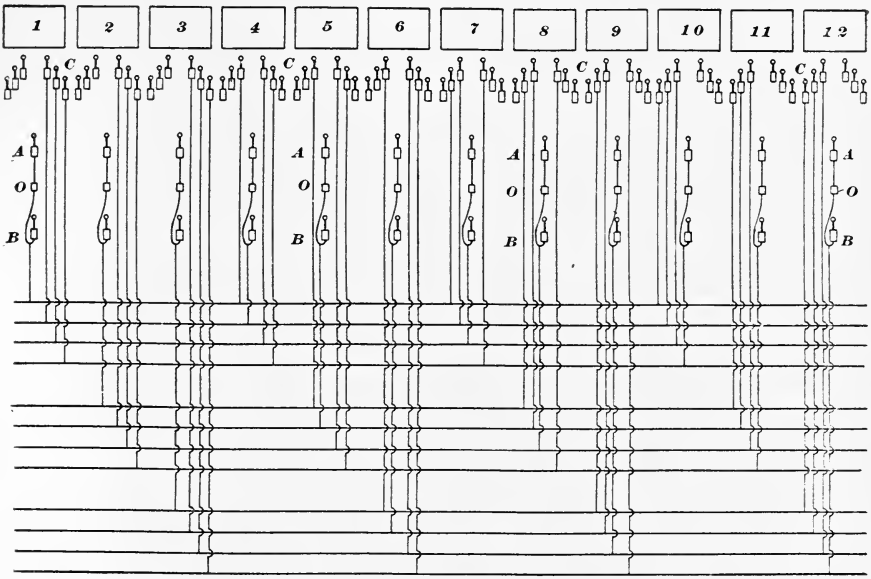


Fig. 189.—General Scheme of Western Transfer System.

necessary switching apparatus for enabling an operator to listen in and to ring out over either cord as desired. Connected with each of these sets of plugs is a trunk line to which is connected at every third section a transfer plug, *C*, as shown. Thus, a pair of plugs, *A* and *B*, shown at section 1, is connected by means of a trunk line to a transfer plug at section 4, another at section 7, another at section 10, and so on. A careful consideration of this figure will show that the same is true for each pair of plugs, *A* and *B*, at the other boards. Fig. 190 shows in greater detail one pair of plugs, *A* and *B*, connected by a trunk line to the several transfer plugs according to this system. The plugs, *A* and *B*, are in this case at section 4, while the transfer plugs, *C*, *C*, *C*, are at sections 1, 7, and 10, or in other words, at every third section on each side of section 4. The form of circuit-changing lever *L* is here shown for convenience only, and serves to illus-

trate the principle, but not the actual connections in this system. By throwing this lever to the left, its two springs are connected with an operator's circuit through the secondary winding of the induction coil, as shown, while when the lever is thrown to the right the terminals of the generator, *G*, are connected with the plug circuit. The circuit-changer actually used in this cord circuit is the one of the Western Telephone Construction Company, described in Chapter XV. The operator

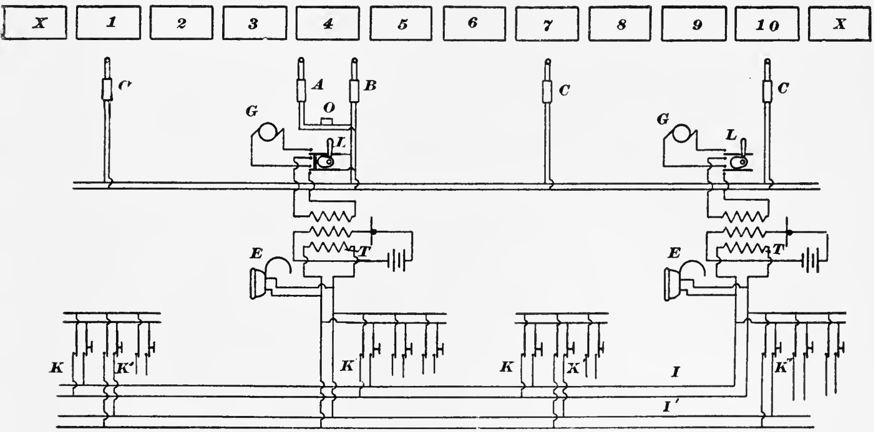


Fig. 190.—Transfer and Instruction Circuits.

pulls the lever forward to ring the called subscriber, pushes it from her to ring the calling subscriber, and presses it downward to listen in.

The system can now be more readily understood by describing its operation. If a subscriber whose line terminates in section 4 calls up, the call is answered by the operator at that board by inserting one of her plugs, *A*, the insertion of this plug restoring the shutter mechanically. The operator then throws the lever *L*, to the left, connecting her telephone set, *E*, with the line of the subscriber calling. Having learned the want of the subscriber, who we will say is 1001, the operator at 4 depresses the key, *K*, which connects her telephone set with an instruction circuit, *I*, terminating in the telephone set of the operator at section 10. The operator at section 4 is thus enabled to communicate with the operator at section 10 over this circuit, and the former informs the latter of the number desired and of the particular transfer plug, *C*, she is to use in making this connection. The operator at section 10 then takes up the plug, *C*, designated and inserts it into the jack of the called sub-

scriber, the operator at section 4 meanwhile holding the lever, *L*, of the particular plugs used, into the ringing position. As soon as the connection is completed at section 10 the first operator is informed of the fact by the operation of a buzzer placed in the cord circuit so that she knows that the signal has been properly transmitted to the line of the subscriber 1001. After the conversation is completed, one or both subscribers ring off, which throws the clearing-out drop, *O*, and informs the operator at section 4 that a disconnection is desired. She therefore removes her answering plug and places it in the socket, informing the operator at section 10 to do likewise. It will be seen that, in addition to the transfer lines extending from the answering and calling plugs at each board to transfer plugs at each third board therefrom, a system of instruction circuits is also provided, each circuit terminating in an operator's set at one board and connected with push-buttons at every third section therefrom, so that an operator is enabled to communicate only with those operators located at every third section from her own board. This peculiar arrangement serves several advantageous purposes, among which is the reduction of plugs necessary for the successful operation of the board and also the reduction of the number of operators talking over any one instruction circuit. It moreover enables any operator to reach, by means of her own calling plug or a transfer plug handled by another operator, any portion of the board. For instance, if a subscriber calling on section 4 desires connection on section 3 or section 5, the operator at section 4 will complete the connection herself by the use of the calling plug, *B*, as she can readily reach any jack on her own section or on that at her right or left. We have seen how a connection is made between section 4 and some section at which one of the transfer plugs of that section is located. If, however, the subscriber on section 4 had called for a subscriber at section 9 the operator at 4 would have signaled the operator at 10, who would then have completed the connection, using transfer plug, *C*, with her left hand. If the called-for subscriber had been upon section 8, operator No. 4 would have signaled No. 7, who would have used a plug, *C*, at her section with her right hand to complete the connection. Ten pairs of calling and answering plugs are furnished for each section of 100 drops, each pair being connected by trunk line with transfer plugs distributed through the system as already described.

A system of lamp signals for facilitating the work upon these boards has been devised and used in many of the later exchanges.

Fig. 191.—Western Switch-board at Wilmington, Del.

In this a white light is so arranged in connection with the night-alarm circuit as to be illuminated, upon each board, whenever a drop is thrown. A similar lamp in series with this is also arranged to be displayed on the chief operator's table, thus serving as a telltale to call the attention of the chief whenever a drop remains unattended on any section. A colored lamp is arranged in connection with each set of transfer plugs and controlled by normally open contact points in the plug seats of the transfer plugs and normally closed contact points in the plug seats of the answering plugs. Two lamps are arranged in series in each circuit, one at the set of transfer plugs to which it belongs and the other at the set of answering plugs with which these transfer plugs communicate. Whenever an operator raises an answering plug in order to establish a connection, the lamp circuit is opened at that point by the operation of the contacts in the plug seat. When another operator removes the transfer plug to complete the connection this same lamp circuit is closed at that point by the operation of the contacts in the transfer plug seat. The circuit, however, still remains open at the answering plug seat. When a calling-out signal comes, and the operator removes the answering plug to disestablish the connection, the lamp circuit is closed at its only open point, which lights the lamp in front of each operator. This shows the transfer operator that a disconnection is desired, and also shows the answering operator that the disconnection has not yet been made. The cycle of events is completed when the transfer operator removes the transfer plug and replaces it in its seat, which act opens the lamp circuit at that point, thus putting out both lamps.

The switch-board of the Delmarvia Telephone Company at Wilmington, Del., is shown in Fig. 191. This board embodies all the features mentioned above and is undoubtedly representative of the best exchanges of the Western Telephone Construction Co.

What is known as the Cook-Beach transfer system has been in long use among some of the Bell exchanges of medium size, and the large switch-boards now manufactured by the Sterling Electric Co., Chicago, are operated upon this plan. The subscriber's lines terminate in drops and jacks on the various sections of the board, no multiple connection whatever being used between them. A set of transfer jacks is also provided on each section, these jacks being connected by trunk lines extending to transfer plugs located at the several sections. When a

call is received at any section, the operator answers it by inserting one of her answering plugs into the corresponding jack. Having learned the number of the subscriber called for, she inserts the corresponding connecting plug into the transfer jack connected by a trunk line with a plug at the board where the line of the subscriber called for terminates. She then communicates with the operator at that board, who picks up the transfer plug designated and inserts it into the jack of the called

Fig. 192.—800-Line Sterling Switch-Board.

subscriber. The connection between any two subscribers is thus made complete by the use of three plugs. This style of transfer system has proven its adaptability to good telephone service by long-continued use in both Bell and independent exchanges.

A board embodying this plan of operation is shown in Fig. 192. The line-drops may be seen in the upper portion of the panel of each section, and immediately below them the corresponding jacks. The drops are of the type already referred to in Chapter XIV., and are provided with the restoring feature by which a whole vertical row of shutters are restored by the pressure upon a button below that row. Immediately below the line jacks are shown the transfer jacks, these being of such a nature that when a plug is inserted into any one of them, a signal is

automatically displayed at the other end of the trunk line to which it belongs, notifying the operator at that section that a connection is desired on that line. The listening and ringing keys are of the type shown in Fig. 145. Two trunk lines are provided from each 100-drop section of this board to every other section, this number being found to give an ample number of trunk lines at the busiest portions of the day.

The larger exchanges equipped by the American Electric Telephone Co. use a transfer system somewhat similar to that of the Cook-Beach type, composed of trunk lines extending between the various sections of the board and terminating in jacks at one end and plugs at the other. Such a board is shown in Fig. 193. There are two such trunk lines extending from each

Fig. 193.—1200-Line American Switch-Board.

100-drop section to each other section, thus giving four trunk lines between each two sections—two outgoing and two incoming from any position. These trunk lines terminate in jacks at the outgoing ends, and plugs at the incoming ends. Each operator has, besides the set of regular listening keys, a set of instruction keys, one for each of the other operators, the depression of any one of which connects her telephone set with the set of another operator corresponding with that key. In this way, a call received for a number not within the reach of the answering operator is transmitted to the operator in whose section the line called for terminates, being given by means of the instruction key just mentioned. The calling line is then connected by a pair of cords and plugs to the jack of one of the two transfer lines reaching to the section in which the called-for subscriber's line terminates. The establishment of this con-

nection causes a lamp to light at the other end of the trunk line and shows the operator there which of the two lines is to be used. The drops used are the same as those illustrated in Figs. 161, 162, and 163, the shutter being restored by the insertion of the plug, and again, after it has been operated as a clearing-out signal, upon the withdrawal of the plug from the jack. Calling is accomplished merely by pressing the calling plug to its fullest extent into the jack of the called subscriber.

CHAPTER XXI.

COMMON-BATTERY SYSTEMS.

It is an obvious disadvantage to have a separate source of current at every subscriber's station in an exchange; and it is not to be wondered at that many efforts have been made to centralize not only the transmitter batteries, but the calling current generators as well. By bringing about such a centralization of the sources of energy many desirable results are attained. The idle capital represented by the local batteries and the calling generators is done away with—no small consideration in large exchanges, because the magneto-generator is in itself the most expensive part of an ordinary telephone set. The labor of visiting or inspecting the subscribers' apparatus is greatly reduced; that necessary to repair and renew batteries, together with the expense of material for such renewal, being rendered *nil.* The subscribers' instruments are made neater and more compact. The electrical efficiency of the plant is greatly increased by having a few large units in operation practically all of the time, instead of a great number of small units in operation but a small portion of the time. Lastly, no freezing of the local batteries occurs; there is no spilling of the acids or other chemicals, and no corrosion of the various parts by fumes therefrom.

As indirect advantages attained in the most modern exchanges wherein all sources of energy are centralized, may be mentioned the fact that the labor on the part of the subscriber in obtaining a connection or a disconnection is reduced to a minimum, and the labor on the part of the operator has been so greatly lessened as to enable her to handle with success about twice as many subscribers as with the old system. Most of the advantages enumerated were appreciated by telephone men long ago, and many attempts were made at an early date to realize them in practice. The first attempts involved a return to first principles, doing away with the induction coil and placing the transmitters and receivers of two connected subscribers directly in series in the circuit of the two line wires. In one of these, made in 1881, by George L. Anders, the transmitter batteries were placed in a loop used to connect the circuit of two line wires. In this the

switch-board was of the old cross-bar type, and, while it used no cord circuits, the batteries were placed in series in the connecting wire corresponding to the cord circuit in later exchanges.

This general method, as applied to a board having plugs and flexible cords, is illustrated in Fig. 194, where *A* and *A'* represent

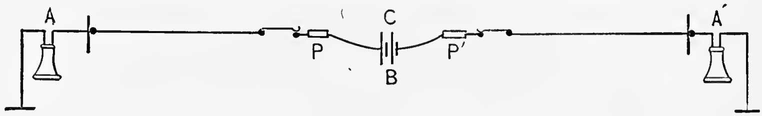


Fig. 194.—Series Common-Battery System—Grounded.

two subscribers' stations connected at the central office, *C*, by a pair of plugs, *P* and *P'*, having a battery, *B*, included in circuit between them. The transmitter and receiver of each subscriber's station are placed in series in the line wire, and each transmitter when operated serves to vary the resistance of the entire circuit formed by the two connected lines, and to thereby vary the strength of the current flowing from the battery, *B*, in such manner as to produce the desired effects in the receivers.

In Fig. 195 the same principle of operation is applied to

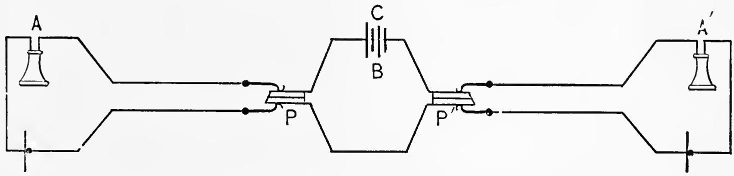


Fig. 195.—Series Common-Battery System—Metallic.

metallic-circuit lines, two of which are shown connected at the central office, *C*, by the pair of metallic-circuit plugs, *P* and *P'*. In both of these cases, in which the battery is included in the cord circuit in series with the combined circuit of the two lines, the use of a separate battery for each cord circuit is, under ordinary circumstances, necessary. This is always true of the grounded system shown in Fig. 194, and is also true of the metallic-circuit system shown in Fig. 195, unless the battery, *B*, is made to have a very low internal resistance. This fact was pointed out by Mr. Anthony C. White, who, in 1890, showed that it was possible to supply all of the cord circuits from a single battery by connecting them in the manner shown in Fig. 196. This involves the bunching together of one side of each of the cord circuits, the battery supplying current in multiple to the

various pairs of lines in use at one time. This figure shows four stations, A, A', A'', and A''', connected in pairs by two cord circuits and pairs of plugs. Fluctuations set up by the transmitter in the line of subscriber, A, will circulate in the combined circuit of the lines of subscribers, A and A'. Similar fluctuations set up by the transmitter at A'' will flow through the circuit of the

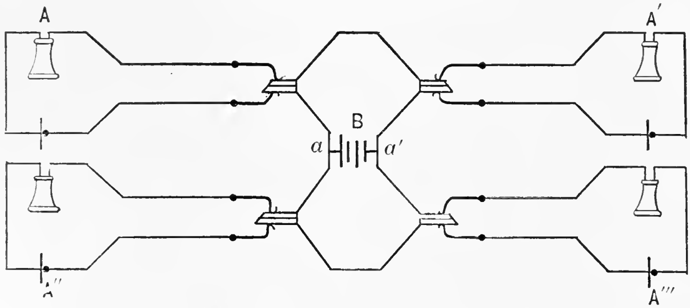


Fig. 196.—Single Battery Series System.

lines, A'' and A'''. The battery, B, and the wire, a and a', in which it is included, are common to both of these line circuits, and if the resistance from the point, a, to the point, a', through the battery is considerable in amount, a part of the fluctuations flowing in the circuit of subscribers, A and A', will be shunted by this resistance through the combined circuits of the subscribers, A'' and A'''. If, however, the resistance from the point, a, to the point, a', is made extremely small, practically all of the current changes will flow through the battery instead of being shunted around through the circuit of the subscribers, A'' and A''', owing to the comparatively high resistance and impedance of that circuit, with its included instruments. The desired reduction in the resistance between the points, a and a', may be accomplished by making the battery, B, of extremely low resistance and by shortening the wire, a-a', which is common to all of the circuits. The former result is accomplished by using a storage battery of rather large capacity, and the latter by joining the various cord circuits directly to the bus-bars with the battery, so as to practically eliminate all resistance in the wire, a a'.

The common-battery arrangement shown in Fig. 197 is one which has come into extensive use and was designed by Mr. John S. Stone in 1892 and 1893. In this figure, A and A' are, as before, two subscribers' stations connected by metallic circuit lines with the central office at C. The transmitter and receiver at each station are connected in series in the line circuit. The

battery, *B*, however, is connected between the two sides of the cord circuit, terminating in the plugs, *P* and *P'*. On each side of the battery is placed an impedance coil, *I* and *I'*, as shown. The action in this case is as follows: the current from the positive pole of the battery, *B*, flows through the impedance coil, *I*, to the point, *a*, where it divides, a part passing through

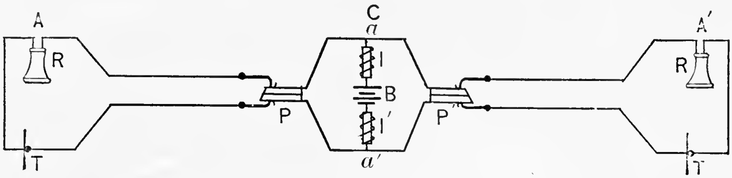


Fig. 197.—Stone Common-Battery Arrangement.

the receiver and transmitter of each of the subscribers' stations. The two parts of the current, after flowing back to the central office through the opposite sides of the lines, unite at the point, *a'*, and flow through the impedance coil, *I'*, to the negative pole of the battery. Inasmuch as the impedance coils are of low ohmic resistance, they offer but little obstruction to the passage of this current. If now the transmitter, *T*, at station, *A*, is caused to lower its resistance, the difference of potential between the points, *a* and *a'*, will be lowered. This will result in a

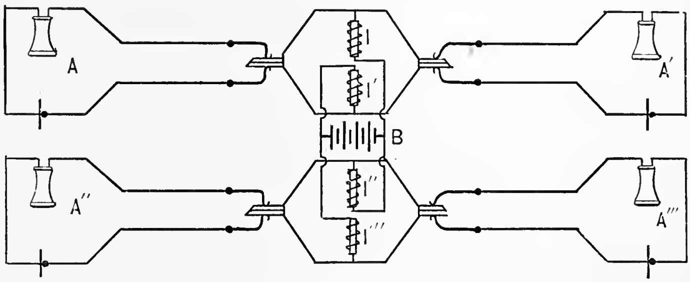


Fig. 198.—Stone Common-Battery Arrangement.

diminution in the current flowing in the line of subscriber, *A'*. On the other hand, if the resistance of the transmitter, *T*, is raised, the difference of potential between *a* and *a'* will be raised, thus causing a greater current to flow through the instrument of subscriber, *A'*. Every fluctuation in the resistance of the transmitter, caused by sounds at either station, will thus cause corresponding fluctuations in the current flowing through the receiver at the other station, thus causing them to reproduce the sounds. The same battery, *B*, is used to supply a large

number of cord circuits, the arrangement being then as shown in Fig. 198, each side of the various cord circuits being connected to the poles of the battery through impedance coils, as before. The fluctuations set up in the circuit of the two subscribers, *A* and *A'*, while perfectly free to pass through these two particular lines, cannot find a path to any other lines, as, for instance, those of subscribers, *A''* and *A'''*, without passing through the impedance coils, *I* and *I'*, and also *I''*, and *I'''*. It is said that by means of this system a direct-current generator can be used in place of the battery, *B*, the impedance coils serving to effectually weed out all of the fluctuations in the generator current which have always been found so annoying in telephone work. Notwithstanding this, however, the storage battery is always used in practice in systems embodying these principles.

Early in 1892 Mr. Hammond V. Hayes devised the method of supplying current to transmitter batteries shown in Fig. 199,

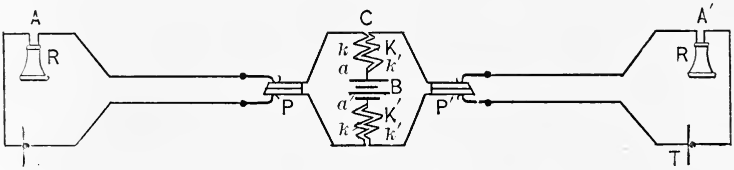


Fig. 199.—Hayes Common-Battery Arrangement.

this having come into very extended use in the Bell Companies, and it has formed the basis of some of the most successful common-battery systems in the world. The apparatus at the subscribers' stations, *A* and *A'*, is arranged as in all of the preceding systems. At the central office, *K K'* are repeating coils each having two windings, *k* and *k'*. The two windings of the coil, *K*, are connected together at the point, *a*, which is connected with the positive pole of the battery, *B*. The other ends of these two windings are connected with the upper contacts of the plugs, *P* and *P*, as shown. In an exactly similar manner the two windings of the repeating coil, *K'*, are connected together at the point, *a'*, which is connected with the negative pole of the battery, *B*, the other two ends of these coils being connected with the lower contacts of the plugs, *P* and *P'*. By this arrangement the battery is included in a bridge conductor between the sides of the circuit formed by the two connected lines, and one limb of each line includes one of the windings of one of the repeating coils. The current from the battery, *B*, will, when the subscribers' receivers are removed from their hooks, divide at

the point, *a*, and pass in multiple through the two windings of the repeating coil, *K*, thence the two portions of the current will pass through the transmitter and receiver of the two subscribers' stations respectively and back to the repeating coil, *K'*, through the windings of which they pass to the negative terminal of the battery.

Any changes in the current in either circuit, produced by the operation of one of the transmitters, will act inductively through the repeating coils upon the other circuit, causing corresponding fluctuations in current to flow through that circuit and actuate its receiver. Thus when the subscriber at station, *A*, is transmitting, the windings, *k k*, will operate as a primary coil of an induction coil of which the secondary is formed by windings, *k' k'*. When the subscriber, *A*, is transmitting, this action is re-

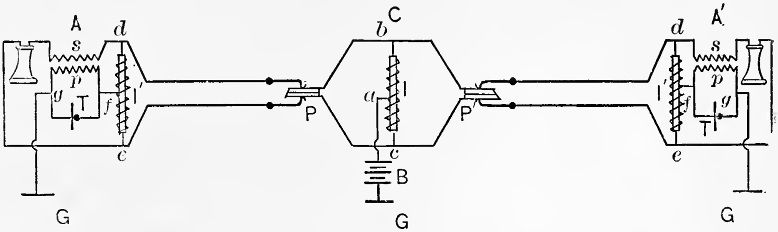


Fig. 200.—Dean Common-Battery Arrangement.

versed, *k' k'* serving as a primary and *k k* as a secondary coil. The transmitter at any station is compelled to vary the resistance of its own line circuit only, and in this way some of the advantages of a local circuit are gained. The two helices of each repeating coil are, under ordinary circumstances, of the same resistance and number of turns, and wound side by side on the same core. The resistance of each helix is usually made rather low, being in the neighborhood of five ohms.

All of the systems so far described have contained the subscriber's talking apparatus directly in series in the line wire. Mr. J. J. Carty is responsible for the broad idea of supplying current to the transmitter of the subscriber's station over the two sides of a metallic line circuit in parallel, using the ground as return. This method, as worked out by Mr. Carty, has been improved upon by Mr. W. W. Dean, who has produced an extended series of inventions embodying this feature. One of them is shown, stripped of details, in Fig. 200, in which *A* and *A'* are two subscribers' stations and *C* the central office. *I* is an impedance coil bridged across the two sides of the cord circuit of the plugs,

P and *P'*. The center point, *a*, of this coil is grounded through the talking battery, *B*. The receivers at the subscribers' stations are connected serially with the secondary coil, *s*, of an induction coil in the metallic circuit formed by the two sides of the line wire. *I'* is an impedance coil bridged between the two sides of the line circuit at each subscriber's station, the center point, *f*, of this coil being connected with one side of a primary circuit containing the transmitter, *T*, and the primary coil, *p*, of the induction coil. The opposite side of this primary circuit is grounded at the point, *g*. Current from the battery, *B*, flows to the center point, *a*, of the impedance coil, *I*, in the cord circuit; thence through the two sides of this coil in multiple to the points, *b* and *c*, on the opposite sides of the cord circuit. From these points the current flows over the two line wires in multiple to the points, *d* and *e*, from which they flow through the two sides of the impedance coil, *I'*, at the subscriber's station to the point, *f*, where they unite. The current then passes to the primary circuit where it again divides, part passing through the transmitter, *T*, and part through the primary coil, *p*. It reunites at the point, *g*, and passes to the ground and back to the battery, *B*.

Variations in the resistance of the transmitter at one of the stations cause more or less of the supply current to be shunted through the primary, *p*, of the induction coil, and these varying currents through the primary induce corresponding currents in the secondary, *s*, placed directly in the line circuit with the receiver. These currents flow over the metallic circuit formed by the two connected lines, and are prevented from flowing through the bridge wires, *d e* and *b c*, by the presence of the coils, *I'*, and *I*, contained therein. In a modification of this scheme Mr. Dean uses a transmitter having two variable-resistance buttons, one of which decreases the resistance of its circuit while the other increases the resistance of its circuit. One of these buttons is placed in each of the branches of a primary circuit such as is shown at the subscriber's station in Fig. 200, each side of the circuit also containing the primary of an induction coil. These are so arranged with respect to the secondary that an increase in current flowing through one of them produces the same effect on the secondary as a decrease of current in the other, and therefore the effects produced by the two variable-resistance buttons of the transmitter are cumulative.

The use of secondary batteries at the subscribers' stations supplied by some source of current either at the central office or elsewhere, has been occupying the minds of inventors since the

very early days of telephony. Storage batteries are in many respects peculiarly fitted for telephone work. Their extremely low internal resistance, and their ability to maintain a constant E. M. F. for a considerable period, are obvious advantages over the primary battery. Charles E. Buell of Plainfield, N. J., was, in 1881, the pioneer in this line. He was followed by Stearns in 1883, Dyer in 1888, and Dean, Stone, Scribner, McBerty, and others, who have accomplished much in this line of work since 1893. The idea of Dyer in 1888 was to charge the storage battery from the ordinary lighting mains of a city, the battery then acting in a local circuit containing the transmitter and primary of an induction coil, in the same manner as when a primary battery is used. In Fig. 201 is shown one of Stone's

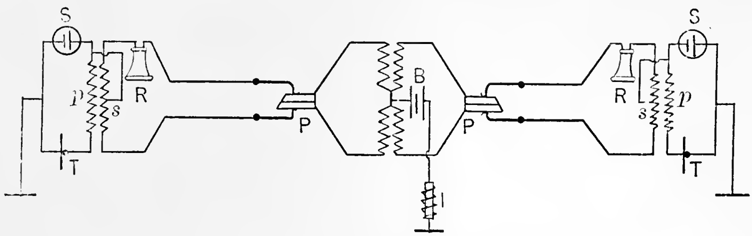


Fig. 201.—Storage Cell at Subscriber's Station.

methods which involves the use of an electrolytic or secondary cell at each of the subscribers' stations. In this, advantage is taken of the fact that if when a storage cell is entirely discharged, a charging current is sent through it, a considerable counter E. M. F. is set up by the cell. The battery, *B*, at central is grounded through an impedance coil, *I*, its other terminal being connected to the center point of a divided repeating coil bridged across the cord circuit of the plugs, *PP*,' after the manner of the Hayes system. Across the terminals of the line wires at each subscriber's station is connected the secondary, *s*, of an induction coil, the center point of which is grounded through a secondary cell, *S*. In circuit with this cell is the primary, *p*, of the induction coil together with the transmitter, *T*. The current from the battery, *B*, passes in multiple over the two line wires, through the transmitter and secondary cell in multiple, and returns by ground. When the transmitter is operated variations in current in the local circuit at the sub-station are produced, and these act inductively on the line circuit containing the receivers, *R*, by means of the induction coil. If the cell, *S*, is discharged the transmitter may be considered as acting solely by means of the

battery, *B*, the counter E. M. F. of the electrolytic cell serving to divert a considerable portion of this current through the transmitter, and thereby accomplishing the same result as if the current originated in the cell, *S*, itself. If, however, the cell, *S*, is fully charged then the transmitter may be considered as working upon the current generated by it, and would so work whether the battery, *B*, were in circuit or not. The fact that the secondary cell possesses practically no resistance and no inductance renders it especially advantageous for this work.

The use of storage batteries or electrolytic cells at subscribers' stations makes possible a full realization of the advantages of the induction coil, but of course introduces the disadvantages of having fluid cells at points remote from the central office. They have been used in some cases with apparent success, but their use has by no means become general.

An electrolytic cell acts in a circuit very much in the same manner as a condenser, and systems have been devised in which condensers were used at the subscribers' stations in place of the cells, *S*, shown in Fig. 201. If we assume these cells to be replaced by condensers, the other arrangements of the circuit being left as shown, current from the battery *B* will pass over the two line wires in multiple, as before, and to ground through the transmitter, *T*, none of it being allowed to pass through the other branch of the primary circuit, by virtue of the condenser. When, however, the transmitter is caused to vary its resistance, the fluctuations in the current set up by it are readily transmitted through the condenser, which offers to them practically no impedance. These fluctuations therefore act inductively upon the secondary coil, *s*, of the induction coil, thus causing corresponding currents to flow in the metallic circuit in the ordinary manner.

Instead of using a storage battery at the subscriber's station, Mr. Dean has proposed the use of a thermal generator, or thermopile, to produce the necessary current. As is well known, if the alternate junctions of a thermopile are heated, the others remaining cooler, an E. M. F. will be set up by the pile. An obvious way of supplying the heat is to wrap the junctures with high-resistance wire, which may be heated by the passage of a current through it. This Mr. Dean does, and his simplest arrangement of circuits and apparatus is represented in Fig. 202, in which the wires of a telephone line are shown leading to the central office of the telephone exchange. The telephone receiver, *R*, and the secondary, *s*, of the induction coil are placed in

the line circuit, as in the instruments now in use. This line circuit is normally open, but is closed by the hook-switch when released from the weight of the receiver. The transmitter, *T*, the thermopile, *C*, and the primary, *p*, of the induction coil are placed in series in the local circuit, which is permanently closed. The resistance coil, *r*, which is here shown in proximity to the thermopile, instead of being wrapped around it, is in a circuit in which is included a generator (either a dynamo or a battery). It is obvious that this generator may be placed at the central station, or that the current may be derived from the street mains of an ordinary electric light circuit. The circuit through this coil, *r*, is

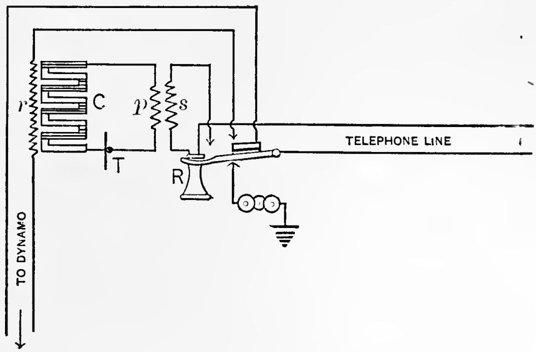


Fig. 202.—Dean Thermopile Method.

normally broken at the hook-switch. When, however, the receiver is lifted this circuit is completed, and the coil, *r*, becoming heated, puts the thermopile into action. The thermopile therefore generates the current only as long as the telephone is in use, and the breaking of the primary circuit becomes unnecessary. The action of the apparatus in talking is precisely the same as if a chemical battery were used.

Mr. Dean has worked out a system by which the current is applied to the thermopile over the two wires of the telephone circuit in multiple, the return being made through the ground. Properly arranged retardation coils prevent the short-circuiting of the voice currents, but allow the passage of the comparatively steady battery or dynamo currents.

All of the principal methods for supplying current from a central source to the subscribers' transmitters have now been pointed out; and in this connection it may be well to show how in large exchanges, not working on the common-battery principle so far as *subscribers* are concerned, a single battery is made to supply all of the *operators'* transmitters. The old method was to use a

separate battery, usually two or three gravity cells, on each operator's transmitter, keeping the circuits entirely separate. Mr. Carty, however, has patented the method shown in Fig. 203, which is largely used, and which gives unqualified satisfaction.

In this B and B' are low-resistance storage cells, preferably placed in multiple so as to make their joint resistance still lower. The primary circuits of the operators' sets, each includ-

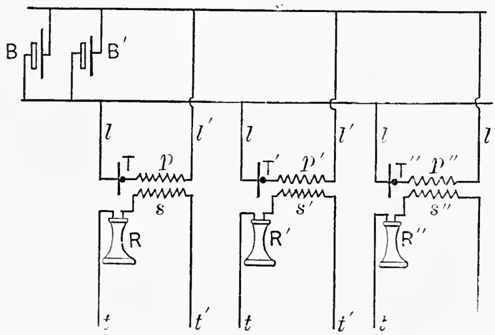


Fig. 203.—Carty Multiple-Transmitter Circuits.

ing a transmitter, T, T', and T'', and the primary winding, p, p', and p'', of their respective induction coils, are connected in multiple between the two heavy bus-bars leading from the terminals of the battery. If the resistance of the battery is very low, and the bus-bars are heavy and short enough, no cross-talk will be noticed between the various operators' sets, because the resistance of the battery and bus-bars is so low in comparison with that of the different transmitter circuits that the drop of potential due to the battery resistance will be inappreciable, and therefore a fluctuation in the resistance of one of the transmitters will cause no change in the potential at the battery terminals. This is an important phenomenon in common-battery work, and should therefore be thoroughly understood. It may be more readily grasped by a simple application of Ohm's law.

Let R_t represent the joint resistance of the transmitters; that is, of the path from one bus-bar through the several transmitter circuits in multiple to the other bus-bar.

Let R_b represent the resistance of the battery and bus-bars, and R the total resistance of the circuit.

Let E represent the total E. M. F. of the battery, and e the difference of potential at the bus-bars.

Then $R = R_b + R$.

By Ohm's law the current is

$$I = \frac{E}{R} = \frac{e}{R_t}.$$

Solving for e we obtain

$$e = \frac{ER_t}{R} = \frac{ER_t}{R_b + R_t}.$$

For a condition of no interference between the various transmitter circuits, it is clear that variations in the resistance of any of the transmitter circuits must not affect the difference of potential at the bus-bars. In other words, e must remain constant. From this it follows that the fraction

$$\frac{R_t}{R_b + R_t}$$

must remain constant, since E, the total E. M. F. of the battery, is unchanging. When the resistance of any transmitter is varied, the total resistance, R_t, of the transmitter circuits will also be varied, and as R_t occurs in both the numerator and denominator of the fraction

$$\frac{R_t}{R_b + R_t},$$

it follows that, in order for this fraction to remain constant, the value of R_b must be infinitely small.

Of course it is impossible in practice to obtain a battery with no internal resistance, but a single 150-ampere-hour cell in good condition will give a sufficiently close approximation for practical purposes.

In actually installing a system of this kind it is well and almost necessary to run the individual wires of the transmitter circuits directly to the terminals of the storage battery, thus practically eliminating all resistance due to bus-bars. The writer had an intimate acquaintance with a case where serious cross-talk occurred under the following conditions: The battery was a single 200-ampere-hour cell of the American type, and there were ten transmitters, each having a resistance of about 10 ohms, the resistance of the primary coils being in each case 0.38 ohm. The bus-bars were each 7 feet long and each composed of two No. 6 B. & S. gauge copper wires in parallel. Serious cross-talk existed

and was only removed when the bus-bars were made of 000 trolley wire, and shortened down to 18 inches.

Another scheme for supplying current from storage batteries to the operators' transmitters, devised by Mr. A. R. Hussey of Chicago, is shown in Fig. 204. In this *B*, *B*, *B* are storage bat-

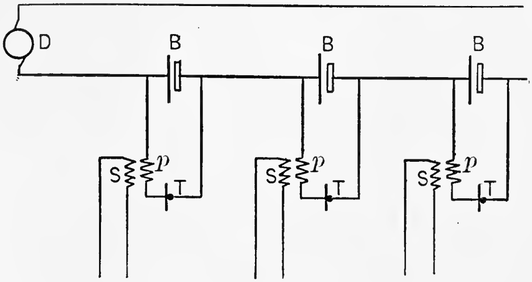


Fig. 204.—Hussey Series-Transmitter Circuit.

teries, of one or two cells, connected in series in circuit with a dynamo, *D*. Looped around each of the batteries is a transmitter circuit containing a transmitter, *T*, and the primary winding, *p*, of the operator's induction coil. This works well and is used by a few independent exchanges.

Mr. Stone has devised a system similar to this by which no batteries are necessary, the current being utilized directly from a dynamo. The circuits are the same as those of Fig. 204, with the exception that condensers replace the storage cells, *B*. Impedance coils are also placed in the supply circuit on each side of the dynamo. Any changes in the resistance of one of the transmitters vary the potential of the charge of the condenser around which it is shunted, and therefore cause fluctuations in the current through the primary, *p*. The current actually flowing through that coil may be considered as the resultant of the steady current from the dynamo and an alternating current from the condenser superimposed upon it. In this case the current remains constant in the supply circuit as a whole, while the variations in current set up by the transmitters flow freely through the corresponding local circuit only. The fluctuations of the dynamo current are with this arrangement not heard at all in the telephones. The dynamo used for this purpose by Mr. Stone was a shunt-wound machine having thirty-six commutator bars, running at a speed of 2200 revolutions per minute and generating 12 volts. The impedance coils were wound to have a joint resistance of 67 ohms and were provided with a soft-iron core, common

to both coils, for the purpose of increasing their electromagnetic inertia. The capacity of the condensers was about 6 microfarads.

One of the chief advantages of common-battery systems is, as has already been pointed out, the readiness with which they lend themselves to all automatic signaling purposes. The methods of supplying current to the subscribers' transmitters having been described, a few systems embodying these methods will be discussed somewhat in detail in order to show the complete working circuits of the exchanges, not only with respect to the means for transmitting speech between the stations, but also by which the various signaling operations are brought about.

The system of Dean, shown in simplified form in Fig. 200, for

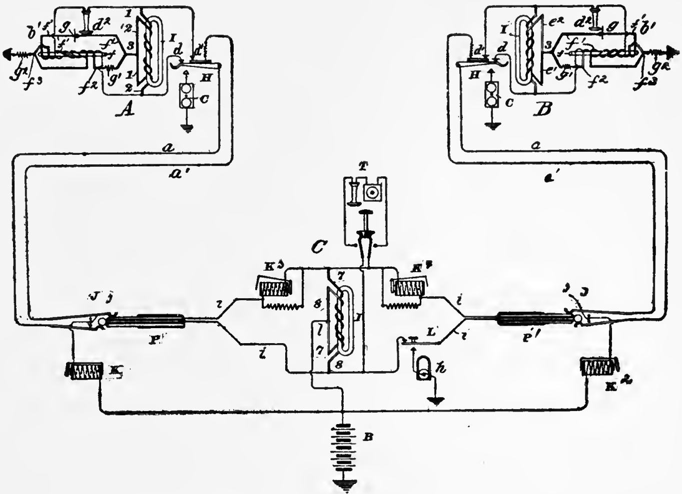


Fig. 205.—Complete Circuits of Dean System.

supplying current from the central station over the two sides of the line wire in multiple, is illustrated more in detail in Fig. 205, which represents the circuits as they would be in actual practice. The impedance coil, *I*, at the central station has two windings, 7 and 8. One terminal of the coil, 7, is connected to the sleeve strand, *i*, while one terminal of the coil, 8, is similarly connected with the tip strand, *i'*, the other terminals of these coils are connected together at the point, *l*, which forms one terminal of the common battery, *B*. In a similar manner the impedance coil, *I'*, at each subscriber's station is provided with two windings, 1 and 2, connected respectively with the two sides of the line circuits, *a* and *a'*, and having their other terminals joined at the point, *f*. The iron cores of these impedance coils are in the form

of flattened rings, in order that a complete magnetic circuit may be provided to increase the retardation of the coils as much as possible. The two windings on each coil consist of about 3000 turns of No. 22 silk-covered wire. As a result of this construction, the coils are of very low ohmic resistance, especially when placed in parallel as they are with respect to the battery currents; but they present a very high impedance to the voice currents flowing in the metallic circuit formed by the two line wires, for it is evident that in order to pass from one side of the circuit to the other these currents would necessarily pass through the two windings of the impedance coil in series. The currents from the battery, *B*, passing through the two windings in parallel, produce no magnetic effect upon the cores of the impedance coils, and therefore these coils are in a condition to offer a maximum amount of retardation. This is due to the fact that a mass of iron when in a neutral magnetic state is more susceptible to a magnetizing force than when the mass is polarized.

At the sub-stations the supply circuit, after being united at the point, *f*, again divides and passes through the two halves of the primary circuit in multiple; but in this case two primary coils are provided, one in each side of the primary circuit, so that the changes in each side of the circuit may be utilized in producing an inductive effect upon the secondary coil. Thus at station, *A*, the circuit divides at the point, *f*, one part passing through the side, f', of the primary circuit containing the transmitter, *g*, and one of the primary coils, represented by a full black line; and the other half passing through the branch, f^2, containing the resistance, g', and the other primary coil, represented by an open line. The two branches, f' and f^2, reunite at the point, f^3, which is grounded through the resistance, g^2. The coil, g', has about the same resistance as the transmitter in its state of rest, so that the supply current will divide equally between the two halves of the primary circuit, and therefore normally produce no magnetization of the core. A decrease in the resistance of the transmitter will cause a greater current to flow through side, f', of the primary circuit and a correspondingly less current through the side, f^2. As the two primary coils in this circuit are oppositely wound, a decrease of current in one of them will produce the same inductive effect on the secondary as an increase in the other, and when these two effects take place simultaneously in the primary coils, the inductive effects upon the secondary coil are added. An increase in the transmitter resistance will in the same manner induce a current in the opposite direction in the secondary.

The limbs, a and a', of each line circuit terminate in contacts on the hook-switch, H, so that when the hook is raised the connection is completed from the line wires through the telephone apparatus already described. When the hook is down, the limb, a', of the line is left open and the limb, a, is closed to ground through a high-resistance polarized bell, C.

At the central office the circuits are as already described, with the addition of the line annunciators, K and K', and the clearing-out or supervisory signals, K'' and K'''. The operator's talking set is adapted to be bridged across the cord circuit by the listening key, while the generator, h, may be connected between the ground and the tip of the calling plug, P', by the key, L.

Assuming the apparatus to be in its normal position, when subscriber, A, desires a connection with subscriber, A', he raises his receiver, R, from its hook, H. This act grounds both sides of his line through his station apparatus. A current from the battery, B, thus flows through the drop, K, to the two sides of the line in multiple, by virtue of the fact that the tip- and sleeve-springs of the jack rest upon the common anvil, j. The current flows through the two sides of the subscriber's circuit in multiple, and to ground, and is of sufficient strength to cause the annunciator, K, to raise its target. The operator seeing the signal inserts the answering plug, P, thus cutting off the circuit through the annunciator, K, and allowing its target to assume its normal position.

The circuits are now completed from the battery, B, through the two halves of the impedance coil, and to ground at the subscriber's station, as already described. The operator then bridges her telephone set, T, across the cord circuit, and communicates with the subscriber. Learning that subscriber, A', is wanted, she inserts the calling plug, P', into the jack of his line and depresses the key, L, which connects one terminal of the grounded generator, g, with the tip strand of the cord, and therefore with the side, a, of the line. A current flows from the generator to ground at the subscribers' station, and operates the polarized bell, C. That subscriber then removes his receiver from the hook, and the two converse over the metallic circuit formed by the two connected lines.

While the subscribers' receivers are removed from their hooks the current from battery, B, flowing through the sleeve strand of the cord circuit energizes the magnets of the clearing-out annunciators, K'' and K''', and causes them to lift their targets. As soon as either subscriber hangs up his receiver this current

ceases to flow, because the line wire, *a'*, with which the sleeve strand is connected is opened at the point, *d'*, on the hook, *H*. This allows the target of the annunciator, *K''* or *K'''*, to fall, showing that that subscriber has ceased to use his instrument.

This represents perhaps the highest development attained in any of the methods for centralizing all energy sources of telephone systems wherein the current for the transmitter is supplied over the two sides of the line in multiple. Although both calling and talking currents are supplied from the central office,

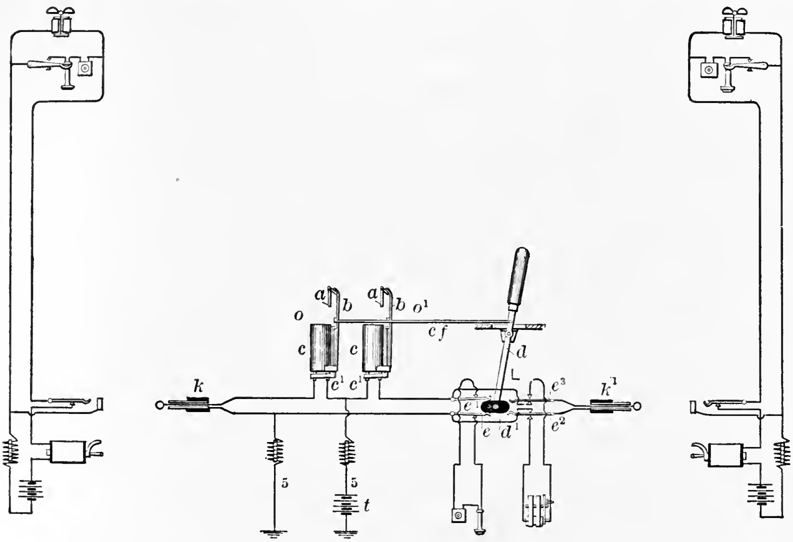


Fig. 206.—Scribner Common-Battery System for Small Exchanges.

and the apparatus at the sub-stations is greatly simplified, and all signals on the part of the subscribers are automatically sent, and all switch-board drops, both line and clearing-out, are self-restoring, this system has not come into general use, probably on account of the still greater simplicity of the Stone and the Hayes systems.

In Fig. 206 is shown the circuits of one of Scribner's common-battery systems used for small exchanges based on the Stone system shown in Fig. 197. This is representative of the most modern practice in this line of work. The line signal is automatically operated by the removal of the subscriber's receiver from its hook, and is effaced by the insertion of a plug into the jack, which act opens the signal circuit at the jack. Current from the battery, *t*, circulates through the impedance coils, 5, and through

the combined circuit of two connected lines, after the manner of the Stone system, already described. The listening and ringing key is so arranged that when the lever, *d*, is moved to the right the wedge, *d'*, will be forced between the springs, *e* and *e'*, thus connecting the operator's telephone across the circuit without breaking its continuity. The springs and the wedge are so formed that the lever will remain in this position until moved by the operator. When pressed in the opposite direction, the wedge is forced between the springs, e^2 and e^3, thus connecting the generator with the calling plug, *k'*. These springs are so formed that the wedge will be forced from between them when the pressure on the lever is released.

Arranged in one side of the cord circuit in the ordinary manner are the supervisory signals, *o* and *o'*, these signals being constructed as shown in Fig. 207, which also gives a better view of

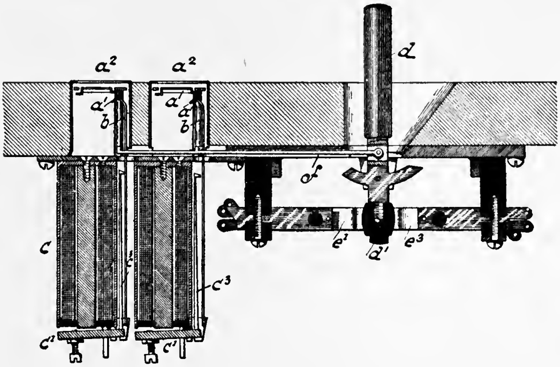


Fig. 207.—Supervisory Signals for Scribner System.

the construction of the listening and ringing key. The indicators or shutters, *a*, are pivoted at their edges in cavities formed in the horizontal key-table. Each shutter is provided with a lug, *a'*, upon which bears the free end of a flat spring, *b*, whose other end is fixed to the frame of a tubular magnet, *C*, arranged under the key-table. This spring tends to bring the indicator into a horizontal position, as shown in Fig. 207. The armature, *c'*, of the tubular magnet, *c*, carries an arm, c^3, which, when the armature is attracted, is thrown against the spring, *b*, thus pushing it out of engagement with the lug, *a'*, on the shutter and allowing it to fall from view. The lever, *d*, of the listening and ringing key is connected by a rod, *f*, with the springs, *b*, of the annunciators in such manner that when the lever is pressed into the listening position, as shown in Fig. 206, the springs, *b*, will be

withdrawn from the shutters, thus producing the same effect as if the magnets were energized, and allowing the shutters to drop out of sight.

With this arrangement the keys are normally left in their listening positions, so that when an operator inserts an answering plug, *k*, into a jack in response to a call, she is at once placed in communication with the subscriber. Having inserted the calling plug, *k'*, into the jack of the called subscriber, she moves the key to the ringing position, and allows it to spring back to an intermediate position in which neither the telephone nor the generator is connected with the cord circuit. This releases the springs, *b*, from the influence of the rod, *f*, but signal, *o*, will not be displayed because current from the battery, *t*, is passing through the line of the calling subscriber, thus energizing its magnet and preventing its display. As the called subscriber has not yet responded, the signal, *o'*, will be displayed because sufficient current cannot pass through the high-resistance bell of the called subscriber to energize its magnet. As soon, however, as the called subscriber responds, current will pass through his line and the signal, *o'*, will be effaced. This condition will be maintained until one or both of the subscribers hang up their receivers, when the currents through the respective supervisory signal magnets will be cut off, their armatures will be released, and the shutters will be displayed by being forced into a horizontal position. The operator will then withdraw the plugs, and will move the lever into the listening position in anticipation of the next call. This latter act will cause the rod, *f*, to pull the springs, *b*, out of engagement with the shutters, thus allowing them to fall.

In Fig. 208 is shown a common-battery system, as applied to a multiple switch-board, embodying most of the latest ideas in telephone exchange work. Two subscribers' lines, *L* and L^2, are shown extending from the subscribers' stations, *A* and *B*, through the spring-jacks, *J* and *J'*, etc., on the various sections of the switch-board. For clearness the two jacks, *J*, are shown in separate portions of the diagram, as are also shown the two jacks, *J'*; but it must be remembered that the jacks, *J*, are upon the same section of the switch-board, and the jacks, *J'*, upon another section. Of course, in a large exchange a far greater number of jacks than two would be connected with each subscriber's line, there being one jack for each line upon each section. The line wires of each metallic circuit, after passing through the jacks, pass through the contacts, 8 and 9, of a line

cut-off relay, *A*, the circuit between them being completed through a battery, *T*, and a lamp signal relay, *B*. *P* and *P'* represent a pair of plugs located at one section of the board, it being understood that this pair and the apparatus shown associated with it would be duplicated many times at each section. Across the tip and sleeve conductors, *a* and *b*, of the cord circuit is bridged a divided repeating coil and a supply battery, *E*, this arrangement being readily recognized as that of the Hayes sys-

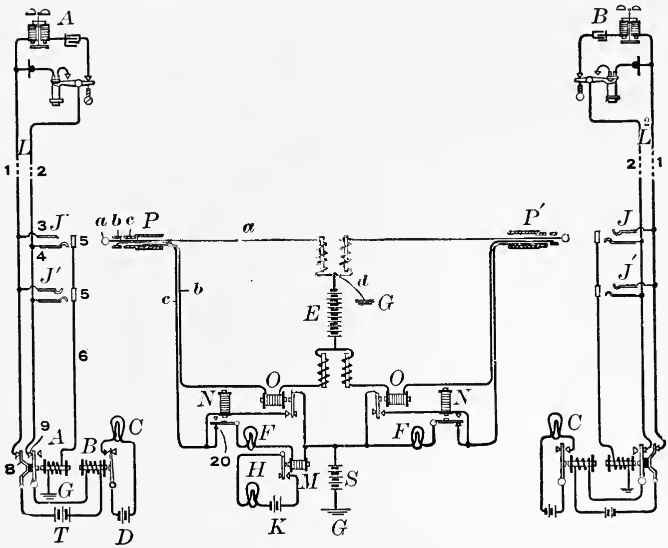


Fig. 208.—Hayes System as Applied to Multiple Boards.

tem. The other apparatus in connection with the cord circuit will be readily understood when its operation is described, it being only necessary to state that the relays, *O*, are contained in the sleeve strand of the cord circuit and serve to control the circuits of the relays, *N*, which in turn serve to control the circuits through the supervisory lamp signals, *F*.

When subscriber, *A*, removes his receiver from its hook, a current from the battery, *T*, flows through the line, actuates the line signal relay, *B*, and causes the illumination of the lamp, *C*. The operator at that station seeing the signal inserts the plug, *P* into the jack, *J*, thus connecting the two sides of the line with the two sides of the cord circuit. This allows current from the battery, *E*, to flow through the circuit of the subscriber's line, and this current causes the left-hand relay, *O*, to attract its armature and thus complete the circuit through the relay magnet, *N*.

The insertion of the plug also completes the circuit from the battery, *S*, to the conductor, *c*, and contact, *c'*, on the plug, thence to test-thimble, 5, of the jack and by wire, 6, through the magnet of the line cut-off relay, *A*, to ground. The current flowing through this circuit accomplishes three purposes: first, the attraction of the armature of the relay, *N*, thus breaking the circuit through the lamp signal, *F;* second, the attraction of the double armature of the relay, *A*, thus cutting off both branches of the line circuit beyond the jacks and extinguishing the line signal, *C;* and, third, the raising of the potential of all of the test-thimbles, 5, connected with that line by an amount equal to the drop in potential through the relay magnet, *A;* so that any operator at another board attempting to make a connection with this line would be warned, upon touching the tip of her plug to the test thimble, that the line was busy by a click in her head receiver. Upon learning the connection desired, the operator applies the tip of the plug, *P'*, to the jack of the called subscriber, and if his line is free she will hear no click, because the test-thimble, 5, will not have been raised to a higher potential than that of the ground, and therefore no current will flow from the tip of the plug through the right-hand upper winding of the repeating coil and to ground by wire, *d*. Upon the insertion of the plug, *P'*, into the jack of the called subscriber the current from the battery, *S*, will pass through the right-hand cord lamp, *F*, through the rearward sleeve of the plug, and by test-thimble to the line cut-off relay of the called subscriber's line to ground. This illuminates the lamp, *F*, and operates the cut-off relay, as before. The lamp remains lighted until the subscriber, *B*, responds to the call, when, upon the removal of his receiver from its hook, the current from the battery, *E*, is allowed to flow through his line. This operates the right-hand relay, *O*, energizes relay, *N*, and thus extinguishes the lamp, *F*, at the same time allowing enough current to flow through the magnet, *N*, to serve for testing purposes and to hold the relay, *A*, closed.

The subscribers now converse by the methods already discussed, and when either of them hangs up his receiver the circuit through that line is broken at the condenser and the corresponding relay, *O*, releases its armature. This de-energizes the relay, *N*, and causes the lamp signal, *F*, to become lighted as a sign for disconnection. Upon removing the plugs from the jacks all apparatus is automatically restored to its normal position.

In circuit with the lamp, *F*, of the answering cord is a relay magnet, *M*, controlling the current of a pilot lamp, *H*, common to

the group of plugs under any one operator. This lamp is placed either on a conspicuous portion of that switch-board or else upon a chief operator's switch-board, and serves at all times to indicate to the chief whether or not that particular operator is properly attending to her clearing-out signals.

This particular arrangement of cord circuit relays was devised by Mr. H. M. Crane of Boston; but the credit for the system as a whole must be shared by several of the engineers of the Bell and of the Western Electric Company.

In Fig. 209 is shown one of Scribner's systems in which the

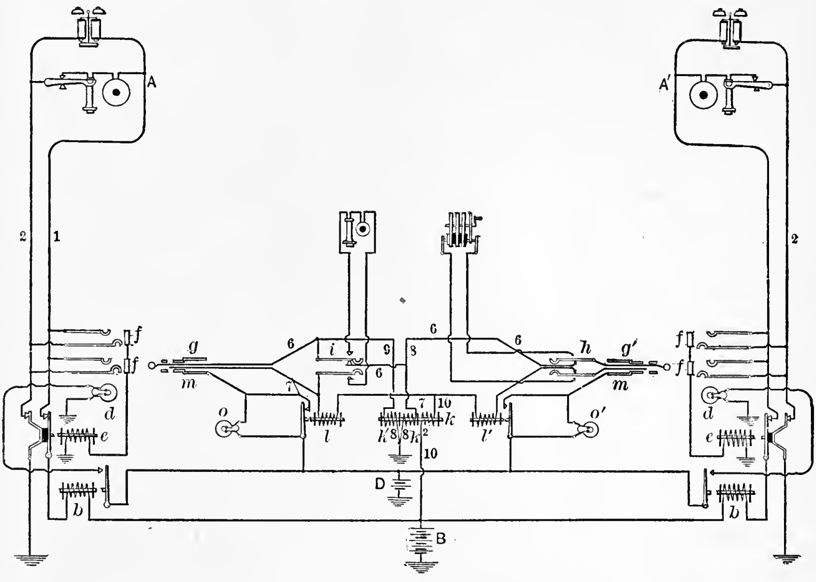


Fig. 209.—Scribner Multiple-Board System.

signaling is not unlike that of the last system described, but in which the transmitter supply is effected substantially by the Stone system described in connection with Fig. 197. In this the polarized bells at the subscribers' stations, *A* and *A'*, are high-wound in order to avoid the necessity for the use of a condenser. These bells when so used are wound to a resistance of 5000 ohms, so that the leakage from the main battery, *B*, is not excessive even when the exchange has a large number of subscribers. The reduction in resistance brought about by the raising of the receiver from the hook causes current from the battery, *B*, to flow through the lamp signal relay, *b*, and through the circuit of the line wire back to ground at the central office.

This operates the lamp signal relay, causing it to attract its armature, thus closing the circuit of the battery, *D*, through the lamp signal, *d*, and causing the illumination of the lamp as a signal for the operator. Upon the insertion of the answering plug the same chain of events is brought about as in the system just described. The cord circuit is connected with the line of the subscriber, while the connection of the sleeve, *m*, of the plug with the thimble, *f*, of the jack allows current to flow from the battery, *D*, through the magnet of the line cut-off relay, *e*, which operates its armature to cut off the line beyond the jacks. The presence of the connection with the battery, *D*, raises the potential of all the thimbles, *f*, of that line, thus causing it to test busy when any operator at another board applies the tip of her testing plug to it. The battery, *B*, will be seen to be bridged across the cord circuit, its positive terminal being connected with the conductor, 7, of the cord, through the impedance coil, *k*, and wire, 10, while the negative terminal is connected with the conductor, 6, through the ground, the wires, 8 and 9, and the two impedance coils, k' and k^2, in multiple.

Inasmuch as the subscriber at station, *A*, has removed his receiver from its hook, the current from the battery, *B*, flowing through the cord circuit operates the relay, *l*, thus short-circuiting the supervisory signal, *o*, and preventing its illumination. The operator communicates with subscriber, *A*, by operating her listening key, thus connecting her telephone set across the cord circuit; and at the same time disestablishing the continuity of the cord conductor, 6, except through the two windings, k' and k^2, of the impedance coil. If she finds that the line of subscriber, A', is not engaged she inserts the corresponding plug, g', of the pair into the jack of that line and operates her calling key, *h*. The insertion of this plug operates the cut-off relay, *e*, as before. On account of the high-resistance bell at the called subscriber's station being still in circuit, sufficient current does not flow through the relay, l', to cause its operation, and therefore the lamp, o', is illuminated and remains so until subscriber, A', removes his receiver from its hook, which act causes a low-resistance path across the two sides of the line, operates relay, *l*, and by short-circuiting the lamp, o', extinguishes it. The going out of this lamp informs the operator that subscriber, A', has responded. The two subscribers then converse by the means outlined in the Stone system in Fig. 197, current being supplied to one side, 7, of the cord circuit through the coil, *k*, of the impedance coil, and to the other side, 6, of the cord circuit through the impedance coils,

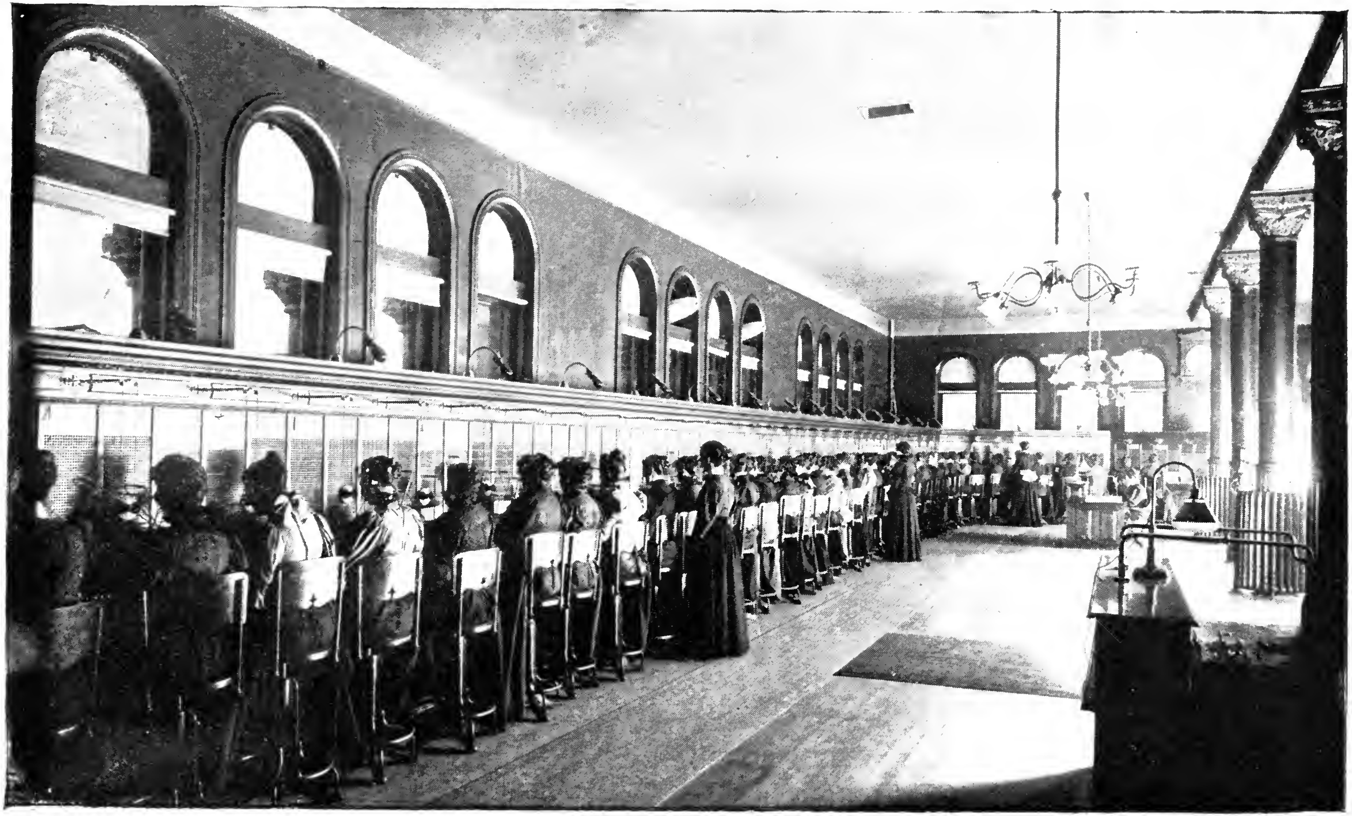


Fig. 210.—St. Louis Bell Exchange. General View.

k' and k^2, in multiple, these having their upper ends connected by means of the contact anvil on the listening key. When either subscriber hangs up his receiver the introduction of the high resistance of his bell into the circuit cuts down the current from battery, B, to such an extent that the corresponding supervisory relay, l or l', releases its armature, thus breaking the short circuit about the supervisory signal, o or o', and causing its illumination. The illumination of both of these signals is a sufficient indication for the operator to assume that the connection is no longer desired, and she therefore removes both plugs, restoring all of the apparatus automatically to its normal condition.

The test in this system is performed by the plug, g', in the ordinary manner. If the test-thimbles, f, of the line tested are raised to a certain potential above the earth by the insertion of a plug into a jack of that line at another board, the current will flow from the thimble through the tip of the plug, to conductor, 6, of the cord circuit, and to ground through the coil, k^2. This will act inductively upon the coil, k', so that a current will flow through it and the operator's telephone, the listening key of course being depressed.

The general appearance of a modern multiple switch-board, equipped with lamp signals controlled by cut-off relays in a manner already described, and operating on the common-battery plan, is shown in Fig. 210, which is taken from a photograph of the new switch-board recently installed by the Bell Telephone Co. of Missouri in their St. Louis exchanges. This board consists of 19 sections, with three operators' positions at each section. It is finished in mahogany, and is about six feet high, four feet wide, with an over-all length of nearly 115 feet. It is at present wired for 4000 subscribers' circuits, and is capable of accommodating an ultimate number of 5600 circuits. Two and one-third sections are reserved for incoming trunks from the various branch exchanges, located in the different districts of the city.

A better idea of the construction of the board may be had from Fig. 211. In addition to the 4000 multiple calling jacks shown on the upper panels of each section there are on the lower panels of the switch-board, as illustrated in the view, 260 answering jacks, appearing only in that particular section and representing the set of subscribers' lines over which the three operators at that section receive their calls.

On the horizontal keyboard, below the jacks just referred to, is a double row of plugs, the rear set or answering plugs being those

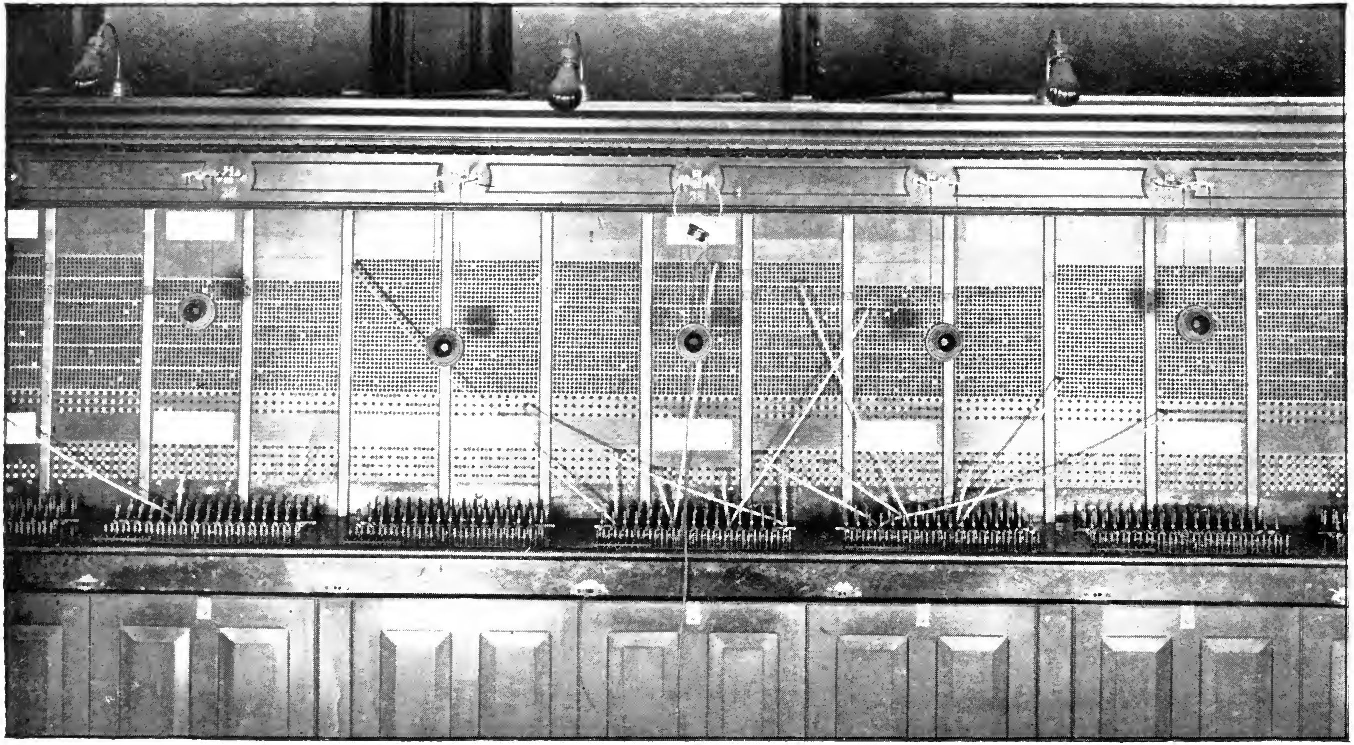


Fig. 211.—Front View of Switch-Board Section.

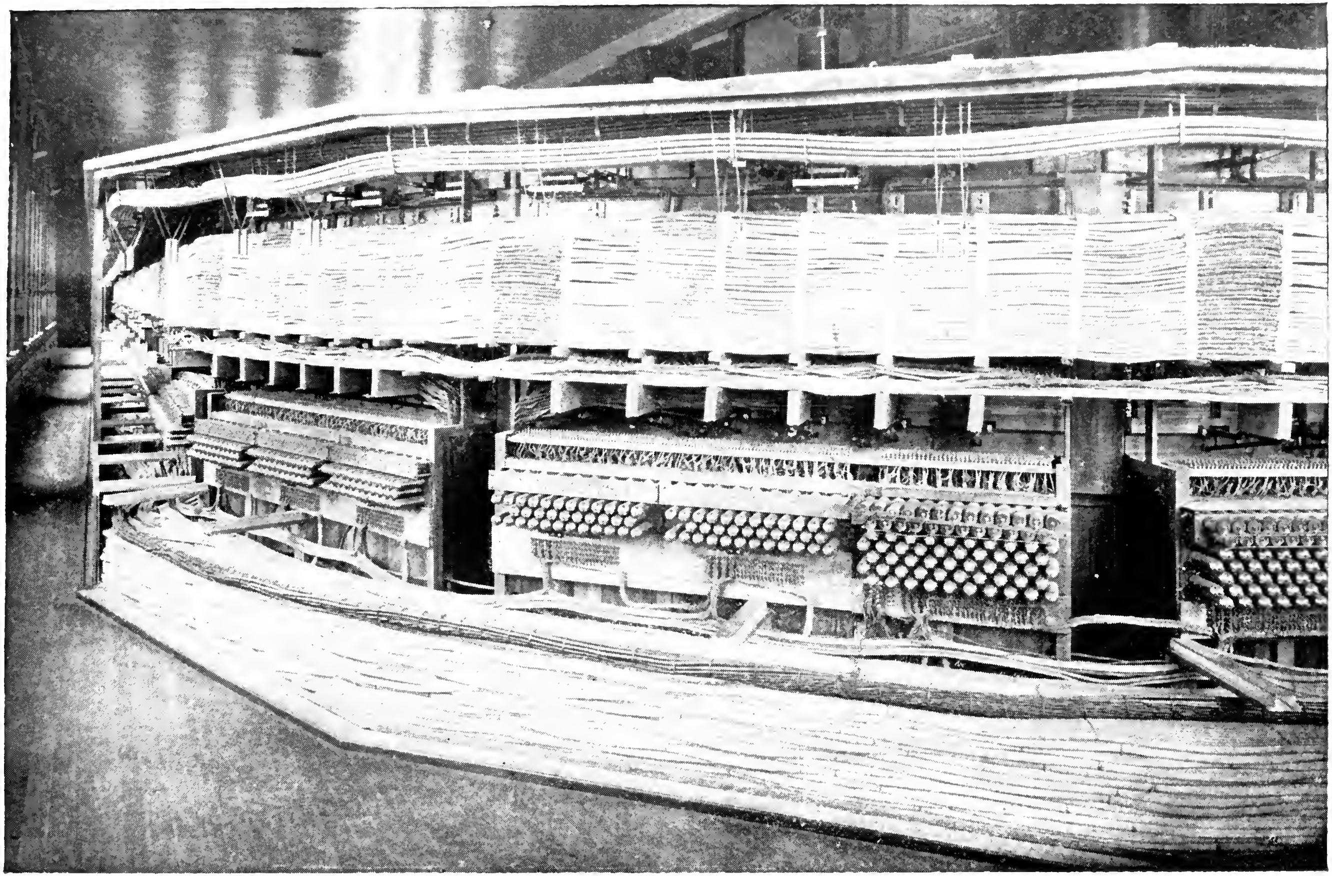


Fig. 212.—Rear View of Switch-Board, Showing Wiring.

first used in the answering jacks in answering a call, and the front set being used for testing and afterward connecting with the line of a subscriber called for, at the multiple jacks above. The listening and ringing keys may be seen directly in front of the plugs.

In Fig. 212 a rear view of the switch-board is shown, giving a clear view of the systematic arrangement of the line and relay

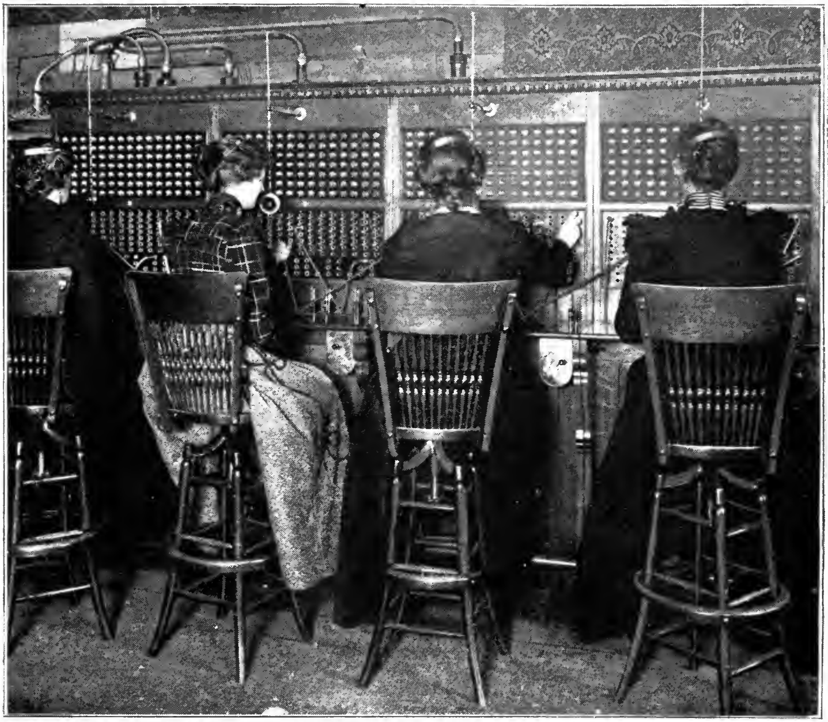


Fig. 213.—Stromberg-Carlson Common-Battery Exchange at Battle Creek, Mich.

cables. The following are interesting facts in relation to the wiring of this exchange: there are five million six thousand feet of wire in the straightaway cables, and nine million two hundred and eighteen thousand feet of wires in the relays and other coils. The number of soldered connections between the terminals of cables on the main distributing board and the operators' switch-board is not less than one-half million.

In Fig. 213 is shown a view of a common-battery switch-board of the Stromberg-Carlson Telephone Manufacturing Co. of

Chicago, which company seems to be doing more in the line of common-battery work than the other independent manufacturing concerns. The circuits of this system present several points of interest, and the writer regrets that he is not at liberty to publish them, having been requested by the makers not to do so.

CHAPTER XXII.

HOUSE SYSTEMS.

Two general plans of installing interior telephone systems for giving service between the various departments of a business establishment may be followed: One of these is to install a switch-board at some central point to which all the lines radiate, and at which they are connected as desired by an operator. In following this plan the switch-boards and instruments used may be of any of the types already outlined for use in small exchanges. The second plan involves the use of what is called an intercom-

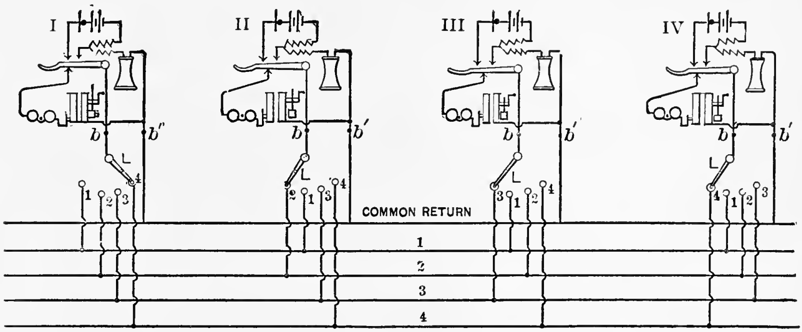


Fig. 214.—Circuits of Ordinary House Systems.

municating or house system, in which the instrument at each station is placed on a separate line, the line belonging to each station passing through all of the other stations. By means of a simple switch arranged in connection with each telephone, the party at any station may at will connect his telephone with the line belonging to any other station and call up the party at that station without the intervention of an operator. This involves the necessity of running at least as many wires as there are instruments in the exchange through each one of the stations; and the simplest way to do this is to run a cable having the requisite number of conduits through each of the stations, all of the conductors in the cable being tapped off to the switch-contact points on each telephone. The connections for a system having four stations is shown in Fig. 214. Each of the telephone

sets embraces the ordinary talking and calling apparatus switched alternately into circuit by the ordinary form of hook-switch. These instruments differ in no respect from the ordinary exchange telephone.

Connected with one of the binding posts, *b*, of each instrument is the pivot of the lever, *L*, which lever is adapted to slide over the buttons, 1, 2, 3, and 4, arranged in the arc of a circle beneath. Each button on each telephone is connected with a line wire, 1, 2, 3, or 4, bearing the same number as the button. The binding post, *b'*, on each instrument is connected with the common-return wire which runs through the same cable as the line wires. During the idle periods of each instrument the lever is kept on the button bearing the same number at that station. This button is usually called the home button, and is for convenience placed at the extreme left of the row of buttons on each instrument. The apparatus as shown represents the condition when station I is about to call station IV. For this purpose the party at station I has moved the lever, *L*, from its home button to button No. 4, thus connecting the instrument at station I with the line belonging to station IV. When the generator at station IV is operated, the current flows from binding post, *b*, to the common-return wire to the binding post, *b'*, at station IV, thence through the generator and call-bell at that station to binding post, *b*, and to lever, *L*, whence the return is made by line wire, 4, to the lever, *L*, and the binding post, *b*, at station I. When the receivers at both stations are raised the talking apparatus is thrown into the circuit over which the calling current was just sent, and the parties converse over the common-return wire and line wire No. 4. Had station IV called station No. I, then the talking and ringing would have been done over the common-return wire and line No. 1. This system may be used with battery call instruments, such as is shown in Fig. 90, in which case no generators or polarized bells will be required.

The great drawback to the system of wiring shown is, however, that the lever at the calling station must always be moved back to the home button when a conversation is finished. If this is not done the instrument at that station will be left switched upon the wrong line, and will not respond to a call sent over its own line from another party. Moreover, when anyone calls a party on the line to which these two stations are left connected, both bells will ring, thus producing much confusion. To illustrate this: if after station I had called station IV, he had left his switch lever, *L*, in the position shown, station II could not call station I

because the instrument at station I would no longer be connected with line 1. Should station II attempt to call station IV, the bells at both stations I and IV would ring because both of those instruments are connected with line No. 4.

Frequently instead of using a rotary switch an ordinary plug and cord are used in place of the switch lever, while the buttons are replaced by simple spring-jacks into which the plug may be inserted. In Fig. 215 is shown such a system, where a plug, *P*,

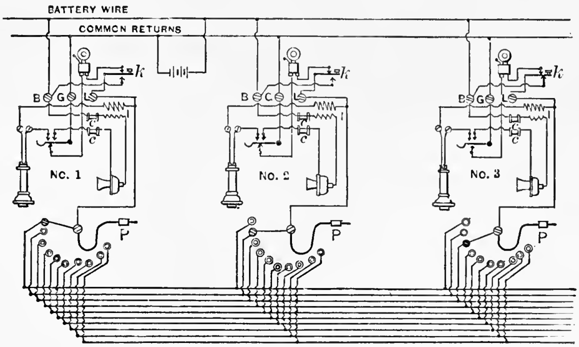


Fig. 215.—Common-Battery House System.

in each case takes the place of the lever, *L*, in Fig. 214. Ten line wires are shown in this figure each connected with ten spring-jacks on each of the telephone instruments; the wiring of but three instruments is shown, this being a sufficient number, inasmuch as all are connected to the circuits in the same manner. This system is for common-battery work, a single battery located at any convenient point being used for supplying both transmitter and talking current to all of the stations. This battery is connected across the common-return and battery wires, which are common to all of the stations and which are placed in the same cable as the line wires. Connected between the common-return wire and the line wire bearing the same number as its station is an ordinary vibrating bell the circuit through which is broken when the receiver is removed from its hook. By pressure upon the key, *k*, at any station, circuit may be completed from the common-return wire through the battery to the plug, *P*, of that station, and therefore if this plug is inserted into the jack belonging to any other station the pressure upon this key will cause the bell to sound at that station. In this way a call may be received or sent. When the hook-switch is raised the transmitter of a station is connected between the battery wire and com-

mon-return wire, so that all of the transmitters at the stations in use take current from the same battery in multiple.

In order to reduce cross-talk between two or more pairs of stations which happen to be communicating at the same time, the small impedance coils, *c c*, are placed in each side of the transmitter circuit at each station. These coils of course cut down the efficiency of the transmission, but they also tend to prevent the fluctuations in current produced in any transmitter from backing up through the battery wire and common-return wire into the local circuits of the other transmitters. Fluctuations produced in the local circuit of any transmitter act induct-

Fig. 216.—Sixty-Point Plug Box and Desk Set.

ively through the induction coil, *I*, upon the talking circuit containing the receiver, the circuit being completed between two stations by the common-return wire and the wire of the station that has been called. This arrangement necessitates the removal of the plug when through talking, as otherwise both of the stations connected would be rung up when either of the stations was called.

As a rule, twenty stations are considered the greatest number that may satisfactorily be served by an intercommunicating system, and when a greater number of stations is to be installed it is better to use a central office provided with a switch-board, with an operator in attendance. The Stromberg-Carlson Telephone Manufacturing Company of Chicago have, however, recently developed this system so that it is said to satisfactorily serve a greater

number of subscribers. In Fig. 216 is shown one of their desk sets in connection with a sixty-point plug board, this system being arranged for intercommunication between sixty stations, that being probably the largest number ever successfully served in one intercommunicating system. The wiring of this system is so arranged that the difficulty due to the subscriber leaving his plug in the wrong spring-jack is practically overcome.

The Holtzer-Cabot Electric Company has overcome the difficulty due to the subscriber calling leaving his switch lever in the wrong position, by the apparatus shown in Fig. 217, this device being

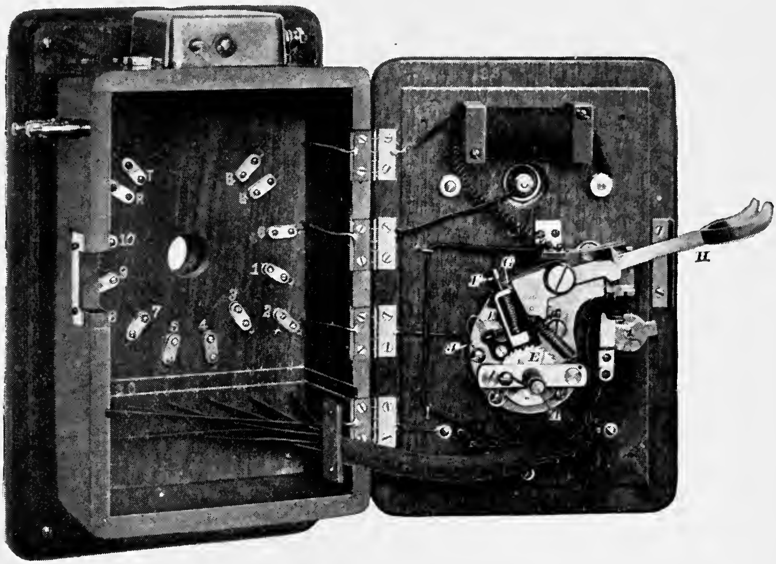


Fig. 217.—Ness Automatic Switch.

the invention of Mr. T. W. Ness. The arrangement is such that when the subscriber hangs up his receiver the switch arm, which is under the influence of a spring, will be automatically released and will fly back to the home position without his volition. In the figure the switch-restoring mechanism is mounted on the inside of the cover of the box, the switch lever itself being mounted on the opposite side. The lever, *L*, at each station, shown in diagram in Fig. 218, is adapted to slide over the buttons, 1, 2, 3, and 4, as in the systems already described. The curved contact-piece, *D*, is so arranged that the lever will not normally engage it, but by pressure upon the handle of the lever it may be brought into engagement with the contact. Referring

again to Fig. 217, *H* is the hook-switch adapted to perform the ordinary functions of connecting the calling and talking apparatus alternately in the line circuit. The switch lever is mounted upon the shaft, *A*, which may be seen passing through the front board of the box and which carries a ratchet-wheel, *E*, of hardened steel. A coiled spring around the shaft tends to rotate it so as to bring the lever always to the home position. *F* is a sliding pawl normally held in its lower position by a coiled spring surrounding it. This sliding pawl serves to hold the lever, *L*, in any position to which it has been rotated, by the engagement with the teeth of the ratchet-wheel, *E*. Upon the

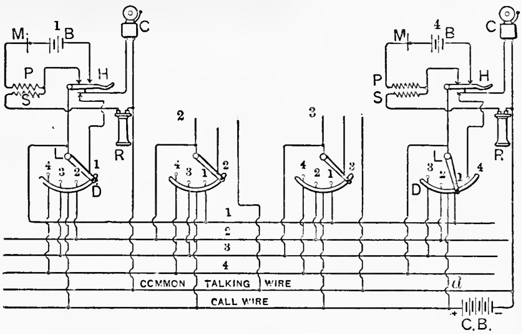


Fig. 218.—Diagram of Holtzer-Cabot System.

short arm of the hook-switch is pivoted a dog, *G*, adapted, when the receiver is placed upon the hook, to engage a notch in the pawl, *F*, and lift it out of engagement with the ratchet-wheel. This allows the spiral spring to return the switch lever to its right-hand position in contact with the home button. After raising the pawl out of the notch on the ratchet-wheel the dog slips out of the notch on the pawl, thus allowing the latter to return into contact with the ratchet-wheel, in order to be ready for the next use of the telephone. In order, however, that the pawl may not engage the ratchet before the lever, *L*, has fully returned to its normal position, a second dog, *J*, is provided, which is pressed by a spring so as to occupy a position under the pin, *p*, carried on the pawl, thus holding it out of engagement with the ratchet-wheel until the rotation of the lever is nearly completed. At this point a cam on the under side of the ratchet-wheel pushes the dog, *J*, out of engagement with the pin, *p*, and thus allows the pawl to drop into position against the ratchet-wheel. It will be seen that this device accomplishes with cer-

tainty what the memory of the telephone user could not be relied upon to do. This entire mechanism is well constructed, all of the parts subject to wear being of hardened steel. The diagram of circuits given in Fig. 218 shows the system wired for four stations operated with common calling battery, and with local batteries at each instrument for talking purposes. This company also manufactures these instruments arranged for the ordinary magneto system, in which case the wiring may be substantially the same as that shown in Fig. 214, but without its disadvantages.

CHAPTER XXIII.

PROTECTIVE DEVICES.

THE matter of protecting telephone apparatus from the damaging effects of currents other than those which properly belong on telephone lines, is not such a simple one as might be at first supposed. The "lightning arresters" found on nearly all telephone instruments are for the purpose of protecting the instruments only from what may be called high-tension currents, such as those produced by lightning. The usual form of this arrester is shown in Fig. 219, in which *A* and *B*

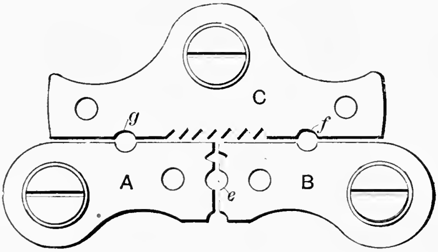


Fig. 219.—Usual Form of Telephone Lightning Arrester.

represent the two line plates carrying two binding posts and forming the terminals of the instrument. The plate, *C*, is connected with the ground. These three plates are not in contact, the idea being that a charge of lightning will jump across the air gap to the ground plate before it will pass through the high resistance and impedance of the instrument coils within. They do some good, but are by no means infallible, as lightning has too many freaks to be kept out by any such simple device. The holes, *e*, *f*, and *g*, are for the reception of a metallic plug, which if placed in *e* short-circuits the instrument, and if in *f* or *g* connects either one side or the other of the line to ground. The placing of the plug in the hole, *e*, affords a very efficient means of protecting an instrument during a storm, but it is subject to the very grave disadvantage that people will forget to remove it after the storm. If but one subscriber is served by a line, no one is hurt but himself, but if it is a party line, con-

structed on the bridging principle, the insertion of such a plug causes a short-circuit which may disable the whole line. Cases are very numerous where a repair man has had to drive perhaps twenty miles in order to tell a subscriber to remove his plug, for, obviously, the subscriber cannot be called up by telephone.

The next most simple means consists in placing in the telephone circuit a fuse-wire of very small current-carrying capacity. These wires are usually mounted upon mica strips, which may be inserted between clips forming terminals of the line and instrument wires. Although largely used, these have not proved at all reliable, but they often save an instrument when the one shown in Fig. 219 fails. Considerable difficulty is apparently experi-

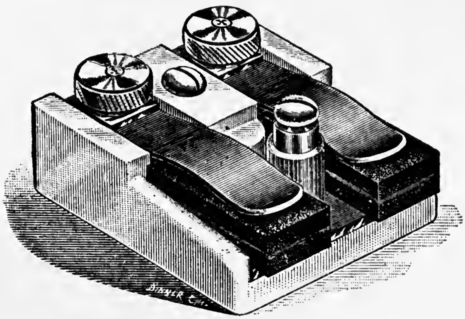


Fig. 220.—American Lightning Arrester.

enced by the manufacturers of very small fuses in gauging them to blow at a given amperage. It is frequently found that "$\frac{1}{8}$-ampere" fuses carry two amperes without showing any signs of blowing. Again, inasmuch as these fuses are necessarily very fine, being not much larger than a hair, it is a very easy matter to break them, thus causing an open circuit the location of which may not be at once apparent. In the case of a high-tension current these fuses usually blow, but frequently start an arc across the terminals, which does the damage to the instrument as effectively as if the line wire was continuous. An instrument is sometimes found burned out with its fuse still intact, although this is uncommon.

Still another form of protector consists of two carbon blocks held apart by a thin disk of mica, one block forming the terminal of the line, the other being grounded. These blocks are usually arranged to slip in pairs between rather strong springs, so that they may be easily removed when desired. One form of these, shown in Fig. 220, represents the double-carbon lightning arrester of the American Electric Telephone Company. The two bind-

ing posts at the top of the figure are attached to the two branches of the line, which are not cut, but run continuously to the telephone instrument, or whatever it is that is to be protected. The third binding post is in connection with the ground plate upon which the two lower blocks rest. The idea in this is that a current coming in over the line will jump across the very small space between the carbons and pass to the ground without harming the instruments.

The arrester shown in Fig. 221 is that used by the Western

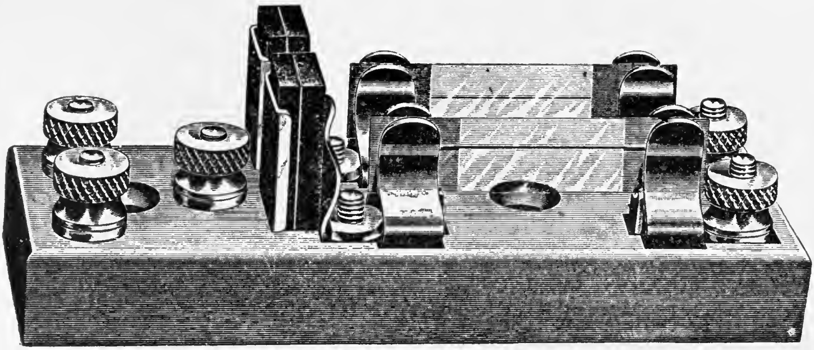


Fig. 221.—Western Lightning Arrester.

Telephone Construction Company, and is a combination of the carbon and the fusible arresters. In this the two line wires of a metallic circuit enter the two binding posts at the right of the cut, from which each circuit passes through the fuse-wires mounted on the mica strips, and then to the vertical springs bearing against the right-hand carbon block. These springs are respectively in connection, by metallic strips underneath the porcelain block, with the two binding posts at the extreme left of the figure. The single binding post is in connection with the two vertical plates holding the carbons, and is grounded. In this the fuse is supposed to blow for any current considered too great for the carrying capacity of the instrument, while, if the current is of a high enough tension to form an arc, it will jump to the ground between the lightning arrester plates. Some advise connecting the fuse on the instrument side of the carbon arrester instead of on the line side, but this is not best in most cases; for, if there is a cable in the line, and a cross occurs at some point beyond it, the current which would flow through the telephone instrument would, owing to the high ohmic resistance of the latter, not be strong enough to injure the cable; but, if the cur-

rent jumps to ground through the carbon arrester a practical short-circuit is formed which might allow a very heavy current to flow through the cable to the ground and thereby damage the conductor. For this reason it is better to have the fuse on the line side of the circuit.

The devices so far described have been designed to cut off all currents from the apparatus to be protected, above a certain maximum value. It frequently happens, however, that a very small current, due perhaps to a cross on the line, will not be sufficient to blow the fuse, and will yet, by reason of a long-continued flow, store up enough heat in a switch-board or ringer coil

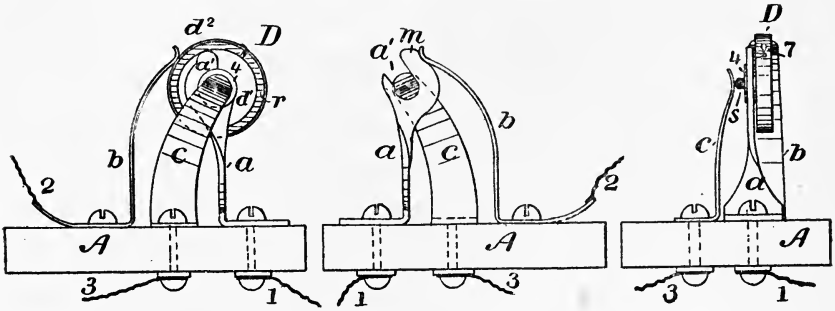


Fig. 222.—Hayes Thermal Arrester.

to char the insulation or burn it out entirely. These currents are the telephone-exchange manager's worst enemies, and are very appropriately termed "sneak currents." They frequently pass all the protective devices placed in the circuit to arrest them, without producing any effect whatever; but, on reaching a close coil of wire, they, by slow degrees, develop enough heat to burn out the coil, or, as has frequently happened, to burn up the whole exchange.

A device to afford protection against such currents as these, types of which have come into almost universal use by Bell companies, is termed a heat coil, and was, so far as I am aware, first introduced by Mr. Hammond V. Hayes of the Bell Company in Boston, Mass. This device is illustrated both in its assembled state and in its various details in Figs. 222, 223, and 224. In Fig. 223 are shown the details of the heat coil proper. A bobbin is formed of the two disks d, and d^1, in the thin flat space, x, between which is wound about 10 ft. of No. 32 B. & S. German-silver wire. On the side, d^1, is carried a metallic shoulder, e, and a flange, 4, forming a deep groove, f, between them. A hole, 8,

is formed through the bobbin, through which projects a hard-rubber pin, *s*. The pin, *s*, is fixed in place by a small amount of easily fusible solder, which normally holds it in the position shown in the left-hand portion of Fig. 224. One terminal of the German-silver wire is attached to the flange, *e*, while the other terminal is attached to an inclosing ring, d^2, of brass.

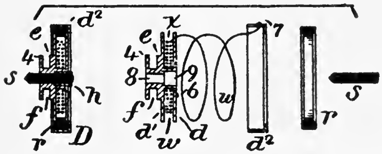


Fig. 223.—Hayes Heat Coil.

The flange, 4, and the ring, d^2, are thus insulated from each other, except for a path through the German-silver wire, *w*.

Three springs, *a*, *b*, and *c*, are mounted as shown, upon a base plate, *A*. The spring, *a*, which forms the terminal of the line, 1, is slotted at a', in such manner as to receive the neck or groove, *f*, of the heat coil, as shown in Figs. 222 and 224. When in place, the spring, *b*, which forms the terminal of the instrument to be protected, rests against the ring, d^2, so that the circuit is

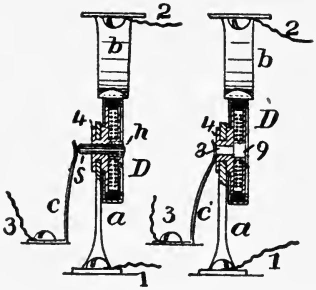


Fig. 224.—Details of Hayes Arrester.

complete from the line wire, 1, through the spring, *a*, flange, 4, German-silver wire, *w*, ring, d^2, and spring, *b*, to wire, 2, to the instrument. When a current stronger than a certain predetermined value passes through the coil, a sufficient amount of heat is generated in the wire, *w*, to melt the solder. This allows the spring, *c*, which is connected by the wire, 3, to the ground, to push the pin, *s*, entirely through the coil, so that contact is made between spring, *c*, and flange, 4, as shown in the right-hand cut of Fig. 224. This at once grounds the line without leaving any air-gap whatever in the circuit, as in the previous

arresters. It has been found advisable, however, to use these heat coils in connection with carbon arresters, and also with comparatively heavy fuses, as will be described later.

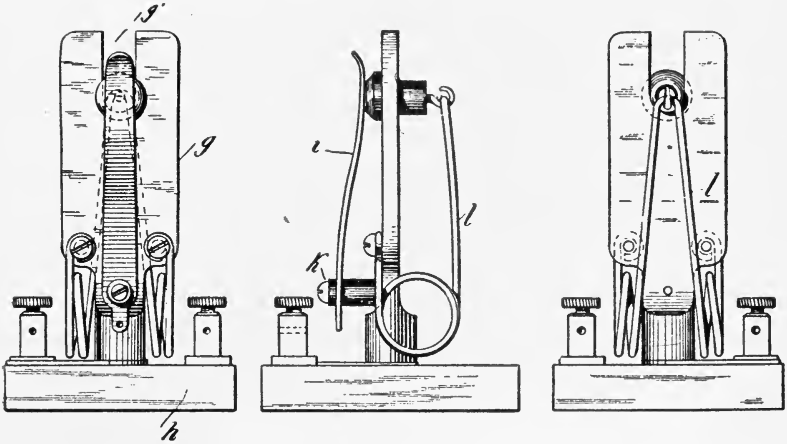


Fig. 225.—McBerty Thermal Arrester.

Another device somewhat similar to this, but adapted to open the circuit instead of connect it with the ground, is shown in Figs. 225, 226, and 227. This is an invention of Mr. F. R. Mc-

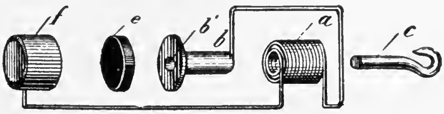


Fig. 226.—Parts of McBerty Heat Coil.

Berty of the Western Electric Company, Chicago. The construction of the coil itself is best illustrated in Fig. 226, in which *b* is a small hollow rivet of conducting material, upon which the

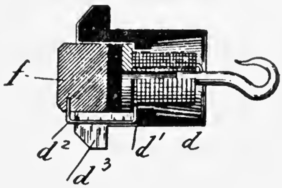


Fig. 227.—Heat Coil of McBerty Arrester.

coil, *a*, of German-silver wire is wound. One end of this coil is attached to the shank of the rivet, as shown, and the other end to a metallic plug or button, *f*. The hook, *c*, is soldered into

the hollow rivet, *b*, and the whole is inclosed in a hard-rubber bushing, *d*, as is clearly shown in Fig. 227. A hard-rubber plug, *e*, is forced into the cavity in the bushing after the rivet has been put in place, and this serves to insulate the head of the rivet from the metallic plug, *f*. A forked standard, *g*, is mounted, as shown in Fig. 225, so as to form a support for the heat coil when in place. A leaf-spring, *i*, insulated from the support, forms one terminal of the line and presses firmly against the plug, *f*. The hook, *c*, of the heat coil is engaged by a spring, *l*, which is held thereby under a considerable tension. This spring forms the terminal of the instrument wire, so that the circuit from the line passes through the spring, *i*, the plug, *f*, the coil, *a*, the hook, *c*, and the spring, *l*, to the instrument. When a current of suffi-

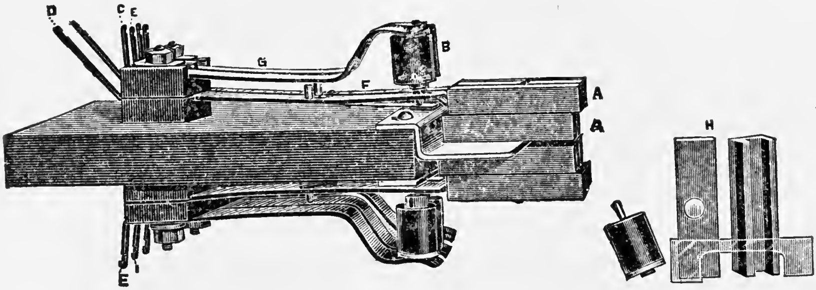


Fig. 228.—Combined Carbon and Heat Coil Arrester.

cient strength to melt the solder passes through the coil, the plug, *c*, is pulled out and the spring, *l*, is thus allowed to assume its normal position. This produces a wide opening in the line, so as to prevent arcing across the gap.

Heat coils may be so adjusted as to be operated by extremely small currents, and they show great uniformity in their operation. By varying the length of the resistance wire or its size, they may be made to respond to a given current in almost any length of time desired. The times of operation for coils constructed in the same manner will seldom vary over 1 per cent. from each other. These coils are usually adjusted to act when subjected to a current of one-quarter ampere for thirty seconds; they are, however, sometimes adjusted for currents as low as .15 ampere. In later coils about 30 ins. of No. 31 B. & S. German-silver wire is used. Heat coils of types similar to these are now built in several different forms and are generally combined with carbon arresters. In protecting switch-boards, it is of the utmost importance that arresters be provided for each side of each drop, and, as economy of space is a very important item in telephone

exchanges, it becomes necessary to arrange them in as compact a manner as possible. Fig. 228 shows combined carbon arresters and heat coils mounted on long strips of iron for this purpose. The principles of operation are the same as those already described, although the structural details are somewhat different. The line wire enters at spring, *D*, and thence passes to spring, *F*, through the heat coil, *B*, to the spring, *G*, and thence to the switch-board wire through terminal, *E*. The spring, *F*, rests in a groove of the carbon block, *A*, which is separated from a similar block by a small strip of mica, shown in detail at the right-hand portion of this figure. This second block rests on a ground plate. An added feature of protection is provided by

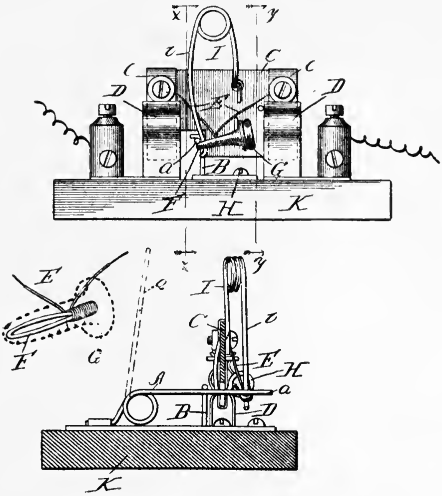


Fig. 229.—Rolfe Arrester.

inserting in one of these carbon blocks a small drop of fusible metal. If an arc occurs between the two blocks, this metal will melt, thus establishing a perfect connection between the two, and grounding the line. In case, however, a smaller current comes in over the line, it operates the heat coil and allows the central rod, which is of metal in this case, to press the light spring attached to the lower side of *F* into connection with the ground plate. The other side of the line is connected to the other side of the switch-board coil in the same manner; the line entering at the terminal, *C*, passes by means of an insulated bolt through the iron frame on which the apparatus is placed, to and through the corresponding heat coil on the lower side of the plate. It passes to the switch-board wire by the terminal, *E*.

Still another type of arrester which is coming into increasing use among the independent companies is that shown in Fig. 229. In this, which is the invention of Mr. C. A. Rolfe of Chicago, the two binding posts which are connected respectively to the clips, *D*, form the terminals of the line wire, and of the wire leading to the instrument to be protected. On an insulating strip, *C*, usually of fiber, are provided the metal ends, *c*, which are adapted to be held firmly between the clips, *D*. A fine-wire coil, *E*, of German silver is connected between the metal end pieces, *c*, its terminals being attached thereto by small screws and washers. The coil, *E*, is imbedded in a mass, *G*, of some easily fusible substance resembling plumbers' wax; the smaller portion of which extends through an eye, *H*, on the plate, *C*. This eye is arranged to support *G*, and to provide a stop against which the head of the button is normally held by the tension of a spring, *I*, secured to the upper portion of the plate, *C*, as shown. *A* is a coiled spring mounted upon the base, *K*, and provided with an arm, *a*, which may be held by a catch, *B*. The relative positions of the springs, *I* and *A*, are such, that if the spring, *I*, is released, it will strike the arm, *a*, of the spring, *A*, and cause it to disengage the catch, *B*. The spring, *A*, will then, in its attempt to rise, as indicated in the dotted portion of Fig. 229, strike the under side of the plate, *C*, and lift it entirely out of the clips, *D*. As the coil, *E*, forms a part of the circuit, a current in excess of that which it is adapted to carry will develop enough heat to melt the wax, and this will allow the head of the coil to pull through the ring, *H*. This in itself usually breaks the wire, *E*, and thereby opens the circuit; but, as an additional protection, the spring, *A*, gives a violent kick, which is sufficient to throw the entire plate, *C*, and its mechanism high into the air. This affords a very effective break between the line terminals—so much so that is almost impossible for an arc to form. This arrester is sometimes termed the grasshopper cut-out, on account of its peculiar action.

CHAPTER XXIV.

DISTRIBUTING BOARDS.

In every central office some means must be provided for distributing the various line wires which enter the exchange to their proper numbers on the switch-board and to enable changes to be made in this distribution as required. If such provision were not made, and the line cables were run directly to the switch-board, the wires in one one-hundred-pair cable, for instance, being led to the No. 1 section, and those of another to the No. 2 section of the switch-board, and so on, it would be necessary, at any time when a change in a subscriber's number was desired, to open the cable, take out the proper wire and fasten it alongside of one of the other cables leading to the proper section of the board. The changing about of wires from one part of a board to another is a very frequent occurrence, and to do it in the manner above suggested would be entirely impracticable. To do it in any manner without a proper regard to systematic arrangement would lead to endless trouble, by producing a tangle of wires, commonly and well termed a " rat's nest."

In order to provide means for the systematic arrangement of the wires, what is called a distributing board or frame is used. These assume a great variety of forms, but the principle on which they are designed is as follows: on one side of the distributing board are placed clips, suitably arranged, in which wires of the line cables may terminate. On the other side of the distributing board is arranged another set of clips or connectors, in which the separate wires of the switch-board cables may terminate. Suppose, for convenience, that the cables entering an exchange are twenty in number, each consisting of one hundred pairs of wires. These wires would pass through suitable office cables to the various terminals on the line side of the distributing board. Suppose further that the switch-board was arranged in twenty sections of one hundred drops each. Then twenty switch-board cables, of one hundred pairs each, would lead from the switch-board terminals to the terminals on the switch-board side of the distributing board. This brings connections from the line cables and also from the switch-board cables, in a permanent manner, to

the various connectors on the respective sides of the distributing board.

The gap between the terminals of any pair on the line side of the distributing board and that of the corresponding pair of wires leading from the switch-board is filled by means of "bridle" or "jumper" wires. Suppose that the line circuit terminating in terminal No. 101 on the line side of the distributing board is to be connected with drop and jack No. 599 on the switch-board;

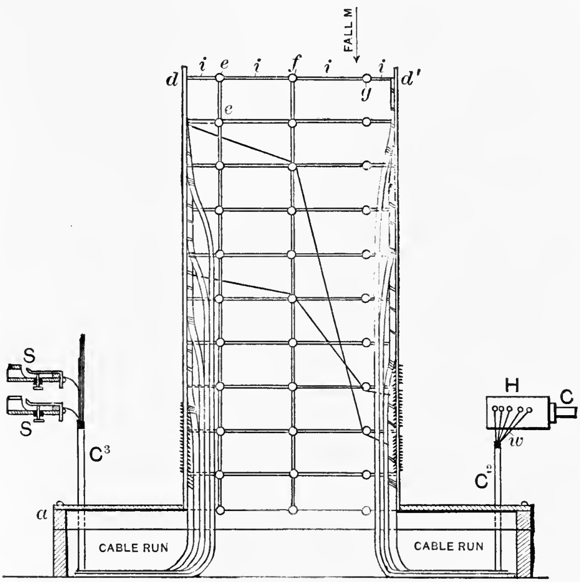


Fig. 230.—End View Hibbard Distributing Board.

then a bridle wire is run from terminal No. 101 on the line side to terminal No. 599 on the switch-board side, thus completing the circuit of that line between the switch-board drop and the subscriber.

One side of the distributing board often carries lightning arresters through which the various line circuits pass before entering the switch-board. These, however, are sometimes placed on a separate board between the line side of the distributing board and the cable heads. Test clips are also often provided on one side of the distributing board. These are usually simple forms of jacks, normally maintaining the continuity of the lines. They are, however, adapted to receive a test plug so that the testing operator may connect his testing apparatus with the line side of the circuit, leaving the switch-board side open, or with the switch-

board side of the circuit, leaving the line side open, or he may merely bridge his testing apparatus between the two sides of the line without breaking its continuity.

Inasmuch as there are in a large exchange several thousand of these bridle wires, means are provided for their systematic arrangement as far as possible. The chief object of distributing boards is to bring all of the confusion among the wires leading from the subscribers to the switch-board into one small place, and then to minimize that confusion as much as possible. This

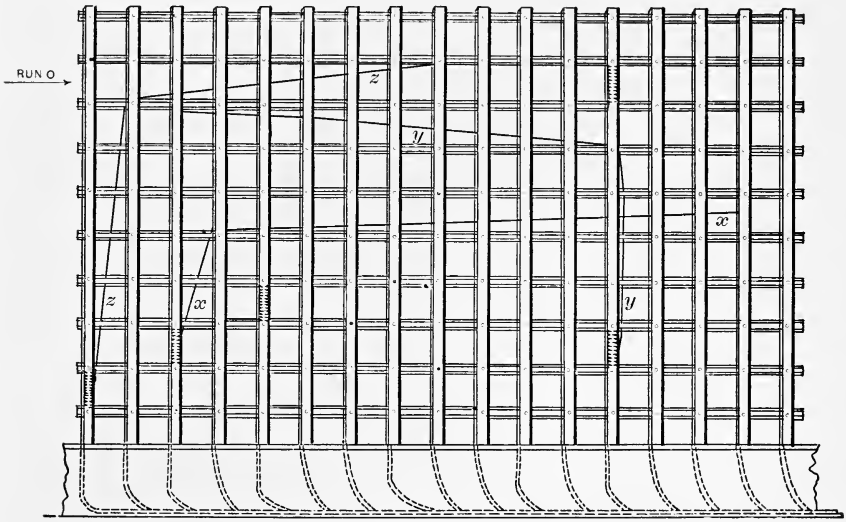


Fig. 231.—Side Elevation Hibbard Distributing Board.

is well done in the Hibbard distributing board, modifications of which are used to a large extent in the Bell exchanges.

This was designed by Mr. Angus S. Hibbard, and is illustrated somewhat in detail in the accompanying figures. The frame is built up entirely of iron pipes, extending in three directions and mounted upon a hollow platform, *a*, shown in Figs. 230 and 231. These two figures represent respectively the end and side elevations of the complete framework, a plan view being shown in Fig. 232. Vertical pipes serve as supports for the structure, and are intersected at short intervals by transverse pipes, *i*, and longitudinal pipes, *e*, *f*, and *g*, extending the entire length of the framework. As a result of this arrangement channels or horizontal runs are formed for the jumper wires between the vertical and the lateral bars, and vertical channels or falls between the sets of intersecting horizontal bars. On the ends of the lateral bars, *i*,

are vertical strips, *d* and *d'*, of insulating material, upon which are arranged the terminals for the various wires in the cables and the jumpers.

The general plan by which the wires are led from the cable heads to the switch-board is shown quite clearly in Fig. 230, where

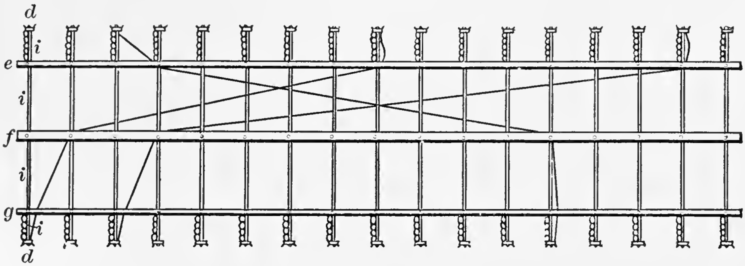


Fig. 232.—Plan View Hibbard Distributing Board.

H represents the cable head carrying the terminals of the line cable, *C*. The various wires, *w*, leading from the cable head are bunched into a cable, C^2, which enters the cable run in the box beneath the frame, and after passing in a horizontal direction to the proper insulating strip, *d'*, is led upward and fanned out, the various pairs of wires being soldered to the outer ends of the terminals on the insulating strip. The method of fanning out is shown in Fig. 233, the covering of the cable being

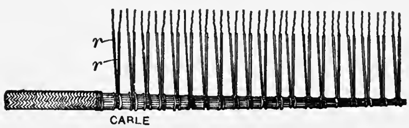


Fig. 233.—Method of Fanning Out Cables.

taken off and the various pairs of wires, *r r*, being led out at intervals corresponding to the distance apart of the terminals on the strip. After being properly formed the cable is laced and varnished or coated with beeswax, after which it is strapped into place and the wires soldered to the terminals on the strip.

The details of these strips and the method of attaching the wires of the cable are shown in Fig. 234, in which *p* and *p'* are the connectors screwed to the strip, *d*. These connectors have outwardly bent lugs, *u*, to which the wires may be soldered. The ends of the jumper wires are shown at *t t'*. In a similar manner the wires leading from the switch-board jack are bunched

into a cable, C^3, which is then led through the cable run and to the proper strip, *d*, of the distributing board, where it is fanned out and connected to similar terminals. The vertical portions of the cables, which are to be fanned out on the distributing board,

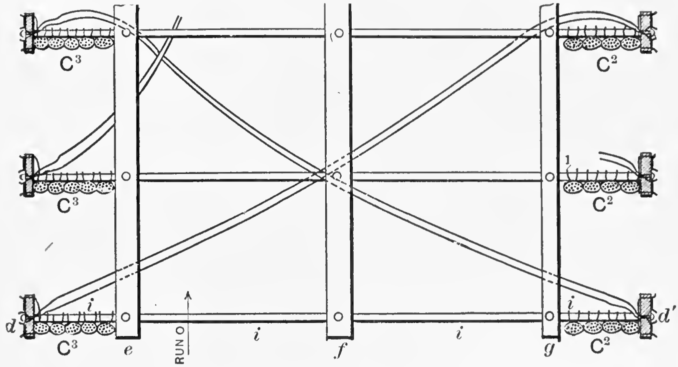


Fig. 234.—Enlarged Plan Hibbard Board.

are supported by the lateral horizontal rods, *i*, by being laced thereto, this being shown quite clearly in the enlarged plan view of Fig. 235. The jumper wires, which are usually formed of No. 22 B. & S. gauge tinned rubber-covered wire in twisted pairs, are at-

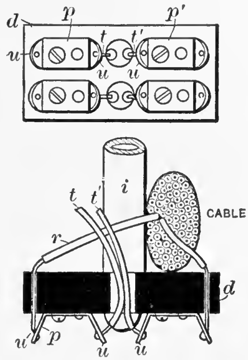


Fig. 235.—Detail of Connection Strips.

tached to the inner ends of the terminals on the line side of the distributing board and led through a hole in the strip and through the proper channels in the framework to the desired terminals on the switch-board side, where they are secured in the same manner.

This arrangement serves to keep the wires fairly open and easy

of access, but for very large exchanges it becomes cumbersome, and has been supplanted by one designed by Messrs. Ford & Lenfest, some of the details of which are shown in Figs. 236, 237,

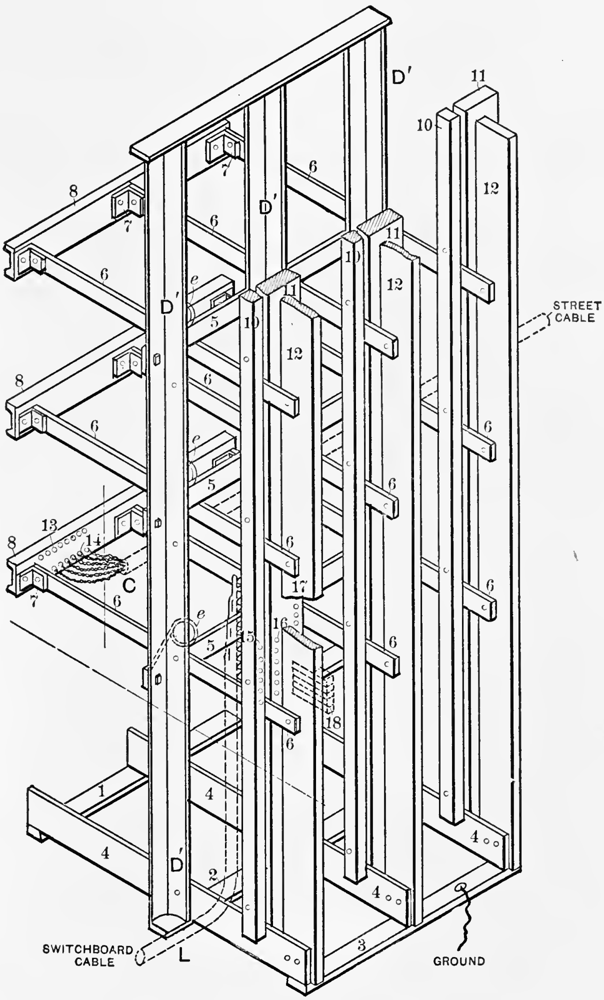


Fig. 236.—Ford & Lenfest Distributing Board.

and 238. This, like the Hibbard board, is in the form of an open framework built chiefly of iron. Iron bars, 1, 2, and 3, to which are bolted plates, 4, form the foundation of the frame. To the face of the plates, 4, are bolted the supporting columns, *D'*, of angle iron, to which are secured all of the other portions of

the frame. Horizontal bars, 6, are bolted to the columns, *D'*, and carry upon one side of the frame horizontal strips, 8, of hard wood, upon which are secured the terminals for the wires of the

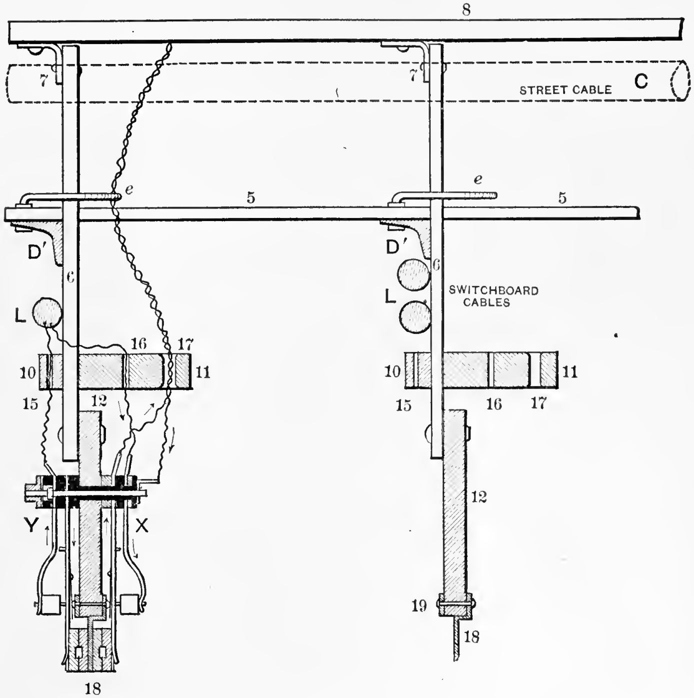


Fig. 237.—Ford & Lenfest Distributing Board.

street cables. A detail of these terminals is shown in Fig. 238, the metallic connectors, *m* and *n*, being secured in place in transverse saw-cuts in a thin strip of board by another strip bolted

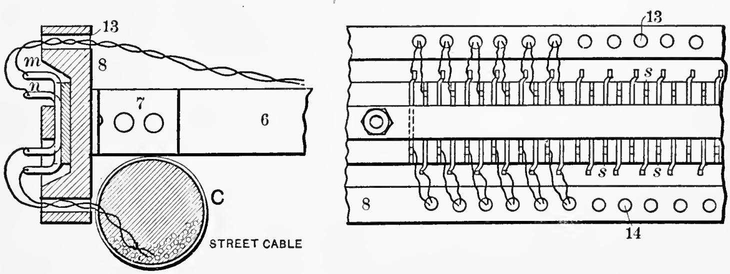


Fig. 238.—Line Terminals, Ford & Lenfest Distributing Board.

over them. A good idea of this general construction may also be had from Fig. 239, which shows a slightly modified construction. Supported upon the other end of the horizontal bars, 6,

are the vertical pieces, 10 and 11, of hard wood and the flat bar, 12, which is of iron. Upon this bar of iron are mounted the arresters, *X* and *Y*, as shown in Fig. 237. These arresters, which are of the combined static and sneak-current type, will be recognized as the same as one of those shown in Fig. 228.

In wiring this distributing frame, the street cables, *C*, are led in a horizontal direction under the strips, 6, as shown in Figs. 236

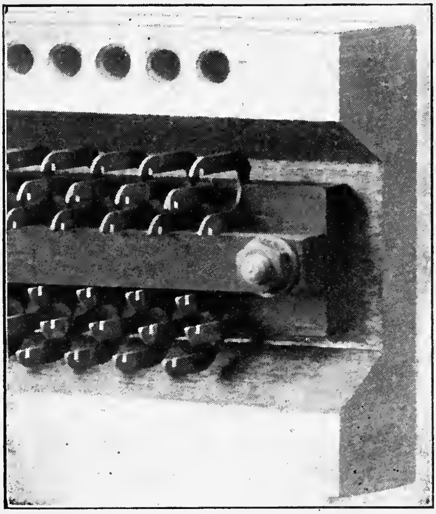


Fig. 239.—Line Terminals, Ford & Lenfest Distributing Board.

and 238. These cables are then fanned out, the various pairs of wires passing through holes, 14, in the under side of the horizontal wooden strip, 8, and secured to the lower ends of the connectors, *m* and *n*. The switch-board cables, *L*, shown in Figs. 236 and 237, are led from beneath up along the sides of the bars, 6, between the supporting bars, *D'*, and the wooden strips, 10 and 11. They are supported in this position by being laced to the horizontal bars themselves. These cables are fanned out, the various pairs passing through holes, 15 and 16, in the wooden strips, 10 and 11, and to their appropriate terminals on the arresters. The connections of the street and switch-board cables are thus as far as possible made permanent. The jumper wires are each led through a hole, 13, in the upper part of the horizontal wooden strip, 8, its ends being secured to the upper portion of the connectors, *m* and *n*, as shown in Fig. 238. The pair is then led in a horizontal direction along the top of the bars, 6, on

the line side of the frame until a point is reached opposite the vertical strip on which the desired switch-board terminal is located. It is then led through an eye or ring, *e*, and through holes, 17, in the vertical strip, 11, and attached to the proper pair of ter-

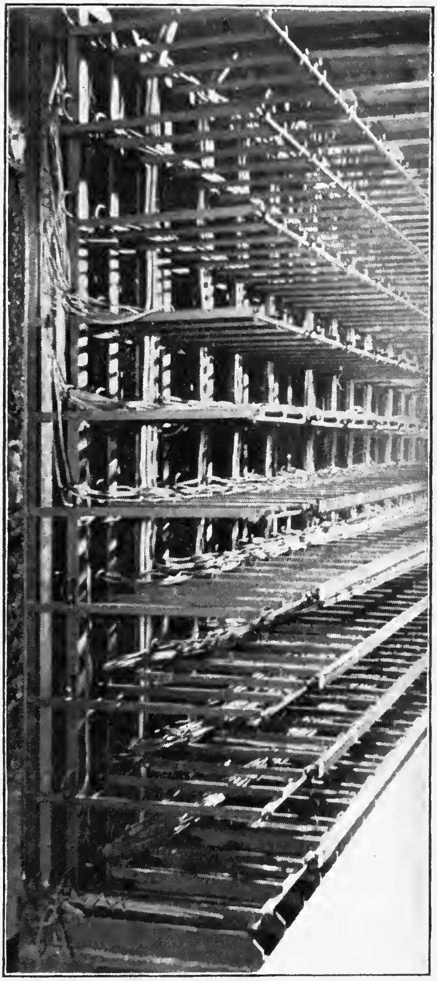


Fig. 240.—Horizontal Side St. Louis Distributing Board.

minals on the arrester through which the connection is made with the switch-board wires.

A distributing frame built upon this general plan is shown in Figs. 240 and 241.

The line cables enter the exchange and are fanned out on the

horizontal side of the distributing frame, as shown in Fig. 240. The terminals on the line side are numbered with respect to the

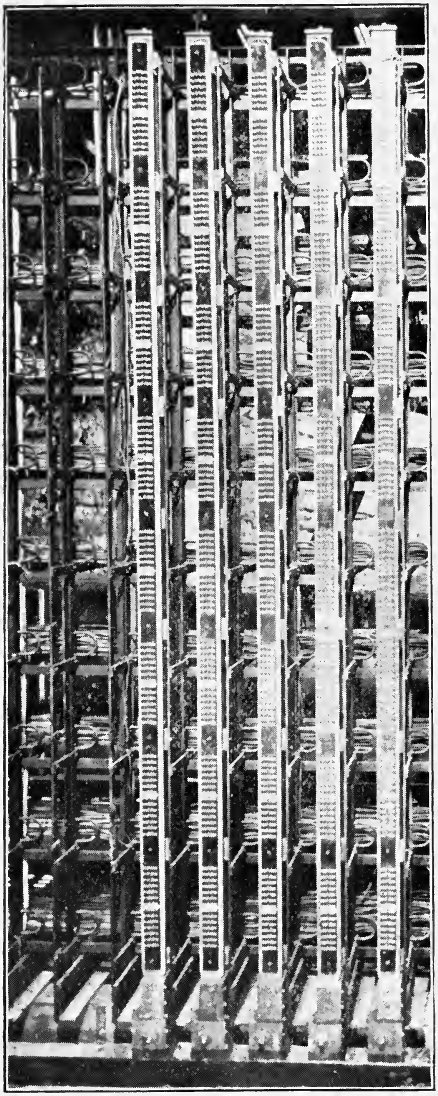


Fig. 241.—Vertical Side St. Louis Distributing Board.

wires in the cables to which they belong. On the vertical side of this board, which is shown in Fig. 241, are placed the arresters, to which lead the wires from the switch-board cables. The

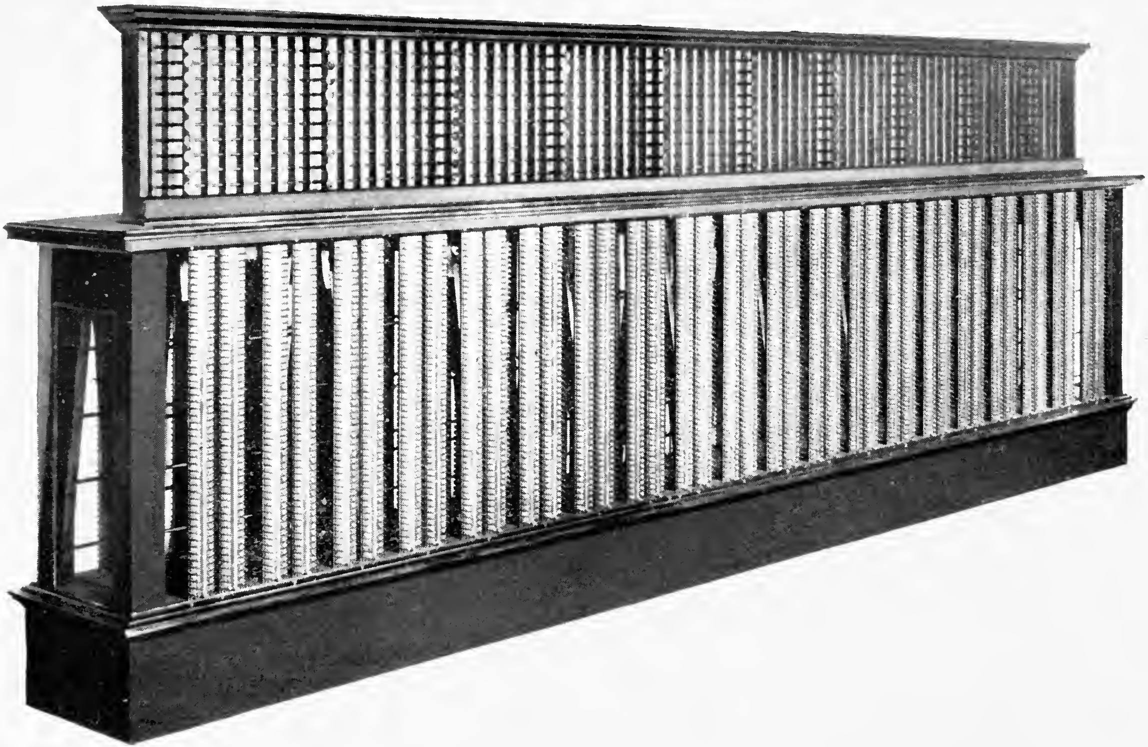


Fig. 242.—Western Telephone Construction Co.'s Distributing Board.

jumper wires connecting the horizontal with the vertical sides are arranged as already described.

In this exchange, and in many other of the more modern Bell exchanges, the wires from the vertical side of the distributing frame do not pass directly to the switch-board, but to an intermediate distributing frame which is similar to the one shown, with the exception that the arresters are left off. After passing through this intermediate distributing frame the cables are again formed up and led to the switch-board. At the main distributing board all of the changes are effected which are made necessary by the change in the location of the subscribers, by the addition of new subscribers and the loss of old ones. The function of the intermediate distributing board is to permit of the rearrangement of the lines upon the switch-board, in order that they may be grouped to the best advantage for quick service. By it the number of calls received per hour by the various operators may be practically equalized so that a part of the operators will not be overworked, due to having an undue proportion of busy lines.

The distributing board manufactured by the Western Telephone Construction Company for some of its larger exchanges is shown in Fig. 242. The side shown in this figure is the line side, to which the line wires from the cable heads are run. Each of the vertical strips seen in the lower section of the structure contains lightning arresters for twenty-five metallic circuits. These arresters consist merely of delicate fuses with suitable clips for holding them. Each strip is provided with a ground plate coming into close proximity with the various clips, so that a high-tension charge may find passage to the ground. The cables leading from the cable heads of the outside lines are afforded room in the box or trough underneath this structure, and each one is bent upward when opposite the proper pair of strips and then fanned out and permanently connected to the proper clips on the lightning arrester strips. All of these connections are made permanent.

In like manner the cables leading from the switch-board are brought into the same trough and bent upward through holes in the baseboard on the opposite side from the line cables, and are then fanned out and connected to the test clips, which are arranged on vertical strips similar to those containing the lightning arresters. These connections are also made permanent. Each jumper wire is run from the proper clips on the arrester side under the nearest one of the horizontal wooden rods shown on

the interior of the lower part of the structure, and then bent upward so as to pass through a hole to a rack above. Inasmuch as the wire is to go to a certain terminal on the switch-board side, it passes through a corresponding opening in the rack and thence in a horizontal channel, formed by the outwardly projecting pins, until it is opposite the terminal to which it belongs on the switch-board side of the board. Here the pair of jumper wires again passes through the vertical rack and down through a small opening and under one of the horizontal rods below, after which it is soldered to the proper pair of terminals. This completes the connection from the outside line to the switch-board line.

The test-clips on the opposite side of the boards and lightning arrester clips are of heavy German-silver springs arranged for the insertion of a double plug in such manner that the testing apparatus may be connected in any desired manner to any line.

The best wire to use for jumpers is No. 20 or 22 B. & S. gauge tinned rubber-covered, twisted in pairs. It is convenient to have the two wires forming a pair of different colors, so as to distinguish between the tip and sleeve sides of the line.

CHAPTER XXV.

PARTY LINES—NON-SELECTIVE.

PROBABLY no branch of telephone work has offered more advantages to the inventor and designer, and consequently received a greater share of ingenious application, than the party-line problem.

A party line is a line having more than two stations upon it. This definition probably needs a little explanation, as a line running from a central office to two stations only is a party line, and we must therefore count the central office as a station, thus making three in all. The term party line is used in distinction from *private line*, which may be defined as a line connecting a central office with one subscriber only, or one subscriber with one other only.

Party lines may be divided into two general classes:

(1) Those where a code of audible signals is employed to enable the various parties to distinguish their calls from those of others.

(2) Those where a system of selective signaling is employed so that any one party may be called up without disturbing any of the others.

The first of these classes may be divided into two general subclasses, according to the connection of the instruments on the line, as follows:

(*a*) Those on which the instruments are connected in series in the line circuit.

(*b*) Those on which the instruments are connected in multiple in the line circuit.

The second or selective signaling class of lines may be divided into three sub-classes, according to the method of selective signaling used, as follows:

(*a*) Those employing step-by-step movements to complete the desired circuit.

(*b*) Those using currents of different strengths or different polarities, or both, for operating the different signals.

(*c*) Those using the harmonic system of selecting—that is, those using currents of various frequencies for actuating the different signals.

The non-selective systems will be first considered.

Probably the first party line ever constructed connected the instruments in the line circuit in series; there are records, however, in the very early days of telephony, of their connection in multiple.

In the series party line the usual form of wiring, such as is shown in Fig. 87, is used. Instruments of this kind are connected *directly in* the line circuit, that is, the line wire is cut and the two terminals so formed are connected to the two binding posts, 1 and 2. In other words, the line circuit enters one binding post of the instrument, passes through the circuits of the instrument, and out at the other binding post and to the next instrument, and so on through the entire circuit.

A grounded line of four such instruments is shown in Fig. 243.

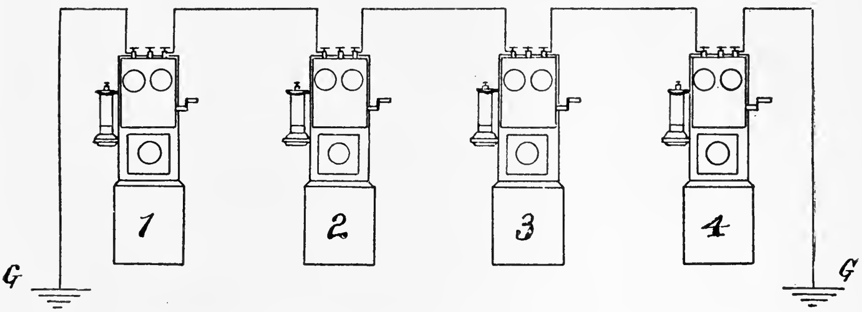


Fig. 243.—Series Grounded Line.

This figure simply illustrates the method of connecting the telephones in the line wire, it being understood that all of the instruments are wired substantially in accordance with Fig. 87.

A little consideration will now show one of the chief disadvantages of the series line. The talking circuit of any two stations engaged in conversation must always pass through the bell magnets of all the other stations. As these magnets necessarily possess considerable impedance, this is a very serious objection, and when a great number of instruments are used the talking becomes very faint. For this reason it is customary to wind the bell magnets on instruments to be used on series lines to a low resistance, rather lower in fact than on the ordinary exchange instruments. Eighty ohms for each complete double magnet is a very good resistance, the winding being of No. 31 B. & S. gauge single silk-insulated copper wire.

It might be thought at first sight that the resistance of the armatures of the magneto-generators would also be included in

the circuit. This was true in the earliest forms of instruments, and proved a most serious objection. Now every good series instrument is provided with an automatic shunt, which, as has been shown, provides that a path of practically no resistance shall always be closed about the generator armature, except at such times as the generator is being operated.

The number of bells that can be rung on a series line is far in excess of the number that can be talked through. Thus fifty instruments would have a combined resistance of 4000 ohms, and if we assume a very high line resistance of 3000 ohms, we have a total resistance of only 7000 ohms, which a good generator could ring through. Fifty instruments in series, however, or even half

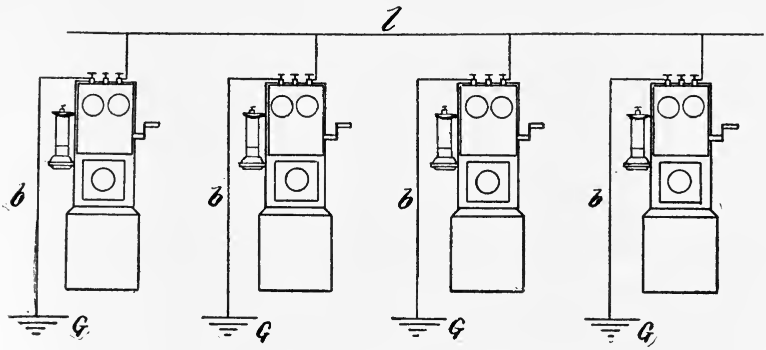


Fig. 244.—Bridged Grounded Line.

that number, without line resistance, give almost intolerable talking service.

Such a line as that shown in Fig. 243 would, moreover, be susceptible to all the inductive trouble to which the telephone is heir. This can, of course, be partly remedied by making the circuit a complete metallic one, and transposing the line at frequent intervals; but even this will not do away with the trouble altogether, as it is impossible to get a proper balance between the two sides of the circuit.

The generators for series instruments should be wound for producing a high electromotive force, inasmuch as there is always a great amount of resistance to be overcome. A good type of generator is one wound with No. 35 single silk-covered wire to a resistance of 550 ohms. Such a generator, with proper mechanical construction and good permanent magnets, will easily ring through 15,000 ohms.

It is well to explain here what is meant by the terms "ten thousand ohm" or "twenty-five thousand ohm" generators. It

means that the generator will ring its own bell through the resistance specified.

The bridging or multiple system of party-line working is now rapidly superseding the series system. Fig. 244 shows the method of attaching the telephones to a single or grounded line according to this plan.

The line wire, *l*, is continuous through all the stations, and each instrument is placed in a separate bridge wire, *b*, or tap to ground.

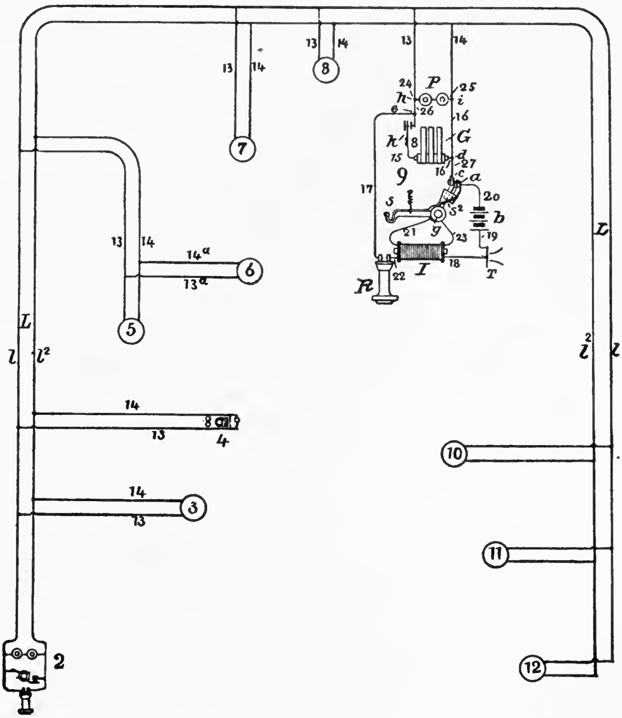


Fig. 245.—Eleven-Station Bridged Party Line.

If the circuit is to be metallic, the ends of the bridge wires, *b*, which are shown connected with the ground, are connected instead with the second line wire.

The circuits of a bridging instrument are shown in Fig. 89, and the line connections of an eleven-station metallic-circuit line in Fig. 245. This latter figure is a reproduction of a figure in the famous Carty patent on bridging telephones. The various instruments, 2, 3, 4, 5, etc., are connected across the two sides, l and l^2, of the line wire, *L*. If the station is not located directly on the

route of the line, it is connected in by running lateral wires, 13 and 14, from its binding posts to the line wires.

In this system the call-bells, *P*, at each station are *permanently* bridged across the two sides of the line, and are made of high *resistance* and *retardation.* The generator, *G*, at each station is in a separate bridge circuit, which is normally open, but closed when the generator is operated. The talking circuit of each instrument, containing the receiver, *R*, and secondary winding of the induction coil, *I*, forms a third bridge circuit, which, like the generator circuit, is normally open.

The telephone circuit of each instrument is automatically closed when the receiver is removed from its hook for use, and this operation also closes the local circuit containing the primary of the induction coil, *I*, the local battery, *b*, and the transmitter, *T*. In order that there shall not be an undue leakage of the voice currents through the permanently bridged call-bell circuits, the magnets of these call-bells are wound to a high resistance (usually a thousand ohms) and are also constructed in such manner that they will have a high coefficient of self-induction. When a generator at any one station is operated, it is connected across the two sides of the line in parallel with all of the call-bell magnets on the line. Part of the currents in this generator will, therefore, pass through each of the call-bell magnets on the line, thus causing them all to operate if the amount of the current generated is sufficient to accomplish this result. The successful operation of this system depends on the fact that a coil possessing a high coefficient of self-induction will transmit with comparative ease alternating or pulsating currents of low frequency, while it will form a practical barrier to similar currents having a very high frequency. The currents generated by the calling generator at any station are of sufficiently low frequency to pass with comparative ease through the call-bell magnets arranged along the line, while the rapidly alternating voice currents impressed upon the line by the telephonic apparatus at any station will be compelled to pass over the main line to the receiving station without being materially weakened by leakage through the call-bell magnets. At the receiving station these voice currents will pass through the telephone receiver and secondary coil of the induction coil, these being connected across the line at that station by virtue of the receiver being off its hook. This path through the receiving instrument is of comparatively low resistance and retardation, and thus practically takes all of the current from the distant station.

The closing of the generator bridge upon the sending of a call may be accomplished manually, as with the key, *k*, in Figs. 89 and 245, or automatically, in much the same manner as that described for breaking the shunt around the generator in the series instrument.

The high retardation of the ringer magnets is obtained by winding them to a high resistance with a comparatively coarse wire so as to obtain a large number of turns in the winding. The length of the cores is increased for the double purpose of getting more iron in the magnetic circuit, and therefore a higher retardation, and also for affording a greater amount of room for the winding. The Western Electric Company wind their coils to a resistance of 1000 ohms, using No. 33 single silk magnet wire. Many other companies use No. 38 wire and wind to a resistance of 1200 or 1600 ohms. This does not give such good results, however, as using the coarser wire and the lower resistance and long cores. Some companies wind, or once wound, their bridging bell magnets partly with German-silver wire in order to make a high resistance at a low cost. They should learn, however, that resistance in itself is not the thing desired, but a great number of turns in the winding, which, of course, incidentally produces a high resistance.

The generators for bridging systems should be designed for quantity of current rather than high pressure, since they have to supply current to pieces of apparatus arranged in multiple. The fact that in some instances a high voltage also is needed must not be overlooked. On long iron lines, heavily loaded, sufficient *current* must be generated to ring all the bells in multiple and sufficient *voltage* to ring the bells at the farthest end of the line. In this case it becomes a question of watts, horse-power, or, more properly, man-power. The winding of the generator is, therefore, a question of vital importance and must vary to meet different requirements. A generator wound to 350 ohms with No. 33 wire makes a first-class one, however, for ordinary bridged lines where copper circuits are employed.

It is undoubtedly better on bridged circuits to use low-wound induction coils, so that the voice currents coming along the line wire will find a much readier path through the talking circuit of the station receiving than through the call-bell bridges at the various stations. In many cases the use of 500- and even 1000-ohm induction coils on bridged circuits renders the impedance of the talking circuits very high, which is exactly what should be avoided.

In connecting a party line with a switch-board much trouble is often caused by the use of an improperly wound annunciator coil. It should be borne in mind that the drop magnet really bears the same relation to the line as the ringer magnets, in the various telephones, and should therefore be connected in the same way. For a series party line the switch-board drop should be wound to about the same resistance as the ringer magnets. If the resistance is made higher, as is often done in the attempt to secure a more sensitive drop, the parties on the line will have much difficulty in talking to each other, because the drop is in series in the line; but if that line is connected with some other line, through the switch-board, this trouble will not exist, as the circuits should be so arranged as to cut out the drop upon the insertion of the plug.

In the bridging-bell system the resistance of the switch-board drop should also be about the same as that of the ringer magnets, and it should possess a high coefficient of self-induction, so as to prevent the short-circuiting of the voice currents. It is frequently impossible, however, to wind drops to 1000 ohms on account of insufficient wire space, and in this case the tubular drop wound to 500 ohms should be used. A properly designed bridged drop may be left permanently bridged across the line, to serve as a clearing-out drop when the subscribers are through talking. In small exchanges, operating party lines, it is customary for the operator at such a switch-board to distinguish between the calls for a connection with some other line, and those which are for parties on the same line, by means of the buzz caused by the vibration of the armature of the drop. It is, therefore, desirable to give the drop armature a rather wide adjustment, so that it will make enough noise to enable the operator to readily distinguish the signals.

On lines where a measured service rate is charged, much loss of revenue is often caused by surreptitious conversations, that is, by parties on the same line calling each other and carrying on their conversation without the knowledge of the switch-board operator, so that no means is afforded for properly charging the use of the line against them. Many arrangements of circuits and apparatus have been devised for obviating this difficulty. One of these, which is suitable only for bridging lines, is to provide at the central office a switch-board drop of extremely low resistance and so arrange it that it will be cut out upon the insertion of the plug. The low-resistance path through this drop acts practically as a short-circuit to all of the high resist-

ance bells on the line, so that when any party rings, nearly all of the current from his generator passes through the switch-board drop, without actuating any of the bells. When the operator plugs in for conversation, or for the purpose of calling up some subscriber on that line, the low-resistance drop is cut out, so that the line is no longer short-circuited. This method cannot be used on long lines, because the resistance of the drop, in addition to that of the line wire, proves high enough to shunt some of the current through the magnets of the bells at the distant end of the line, when parties at that end attempt to signal each other. While the drop would short-circuit the end of the line nearest the switch-board, the instruments at the farther end would not be appreciably affected, owing to the high resistance of the line wire between them and the board.

This method is not, on the whole, very satisfactory, and a better one is to arrange the magnetos at the subscribers' stations to generate a current *in one direction only*, instead of the usual alternating current, and to give the armatures of the bridged call-bells at all of the stations a permanent set or tendency toward the pole which would be rendered stronger by currents in this direction. The switch-board drop, also bridged across the line, is of a non-polarized type, so as to fall when actuated by currents in either direction. Thus, when any subscriber calls, the current will have no effect upon any of the ringer magnets of the other subscribers, because it tends only to pull the armatures closer to the poles toward which they are already attracted, but will cause the switch-board drop to fall in the ordinary manner. Thus, no subscriber can obtain a conversation with any other subscriber without the full knowledge of the operator. The switch-board generator is equipped for sending out currents, either of the opposite polarity from those generated by the subscribers' generators or of the ordinary alternating character, so that the operator may ring up the subscribers at will.

LOCK-OUT SYSTEMS.

A very interesting class of systems, designed to secure a certain degree of secrecy in party-line service, has come into existence during the last few years. In the systems so far described there is nothing to prevent one subscriber from taking his receiver off the hook and listening to whatever conversation other subscribers may be engaged in. The lock-out systems, as they are called, are designed to remedy this evil and also have for their

object the prevention of subscribers desiring to use their instruments from breaking in while the line is already busy, thus ringing in the ears of the parties who are using their telephones.

Mr. C. E. Scribner of the Western Electric Company has, as in nearly every other branch of telephony, been well to the front in this line. One of these systems designed by Mr. Scribner is shown in Fig. 246, which illustrates three subscribers' stations, E,

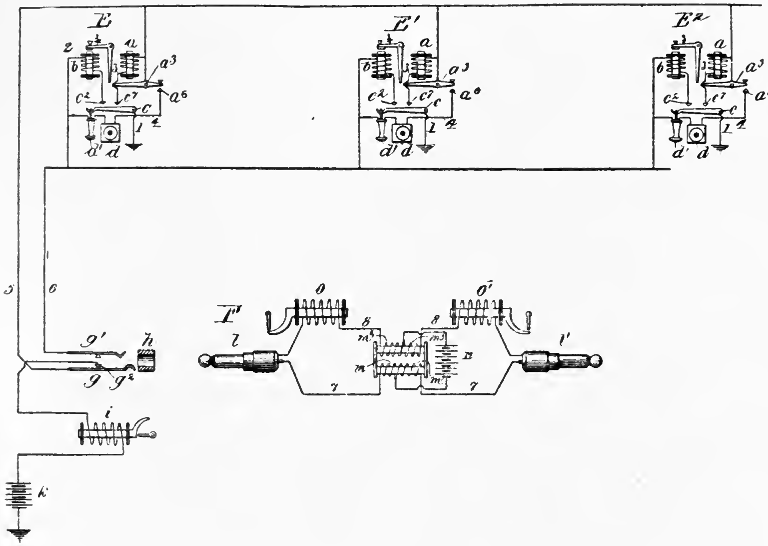


Fig. 246.—Scribner Lock-out Party Line.

E^1, and E^2, connected by the line wires, 5 and 6, of a metallic circuit with the switch-board at the central office, F.

The mechanism for operating the lockout devices at each station on the party line is shown in Fig. 247. In this figure a magnet, a, supported on a bracket, a^1, is provided with an armature, a^2, carried upon a lever, a^3, pivoted as shown. The armature, a^2, is normally pulled away from the core of the magnet, a, by the attraction of gravity, the magnet being mounted with its core vertical. The backward movement of the lever is limited by the stop, a^5, and the forward movement by the contact anvil, a^6, with which it makes contact when the armature is attracted.

Mounted alongside of the magnet, a, is a similar magnet, b, having its armature, b^1, mounted on the short arm, b^2, of a bell-crank lever, b^4. The armature is normally held away from the core of the magnet, b, by the spring, b^5, which bears against the adjustment screw, b^6. When the armature, b^1, is attracted

by its magnet, the long arm, b^4, which normally rests against the back stop, b^7, is pushed sidewise and into the path of the lever, a^3, so as to prevent the upward movement of the latter.

The hook-switch is of the Warner type, and the contacts are so adjusted that the spring, c^2, makes contact with the lever at the point, c^4, before the spring, c^7, makes contact at the point, c^6, when the receiver is removed from the outer end of the hook. The action of these springs is the same as in the ordinary receiver hook, being such that when the hook is depressed the

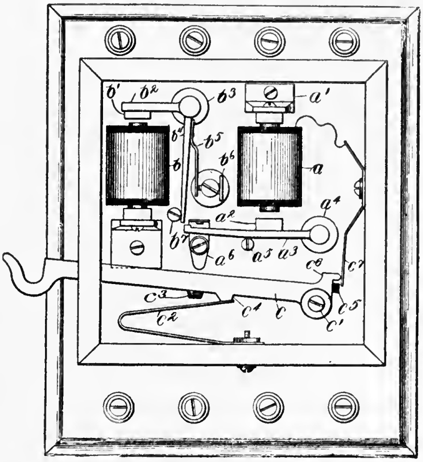


Fig. 247.—Lock-out Mechanism.

spring, c^7, breaks contact with c^6, resting on the hard-rubber lug, c^5, while the spring, c^2, breaks contact with c^4, and rests on the hard-rubber lug, c^3.

Referring now to Fig. 246, and remembering that the various parts in the apparatus shown at the substations, E, E^1, and E^2, bear the same reference letters as those in Fig. 247, the circuits may be traced as follows: The telephone switch-hook, C, is permanently connected to ground by the wire, 1. The wire, 2, leading from line wire, 6, includes the winding of the magnet, b, and terminates in the contact point, c^2, which, it must be remembered, is the contact first made when the hook is raised. The wire, 3, which branches from the main line wire, 5, includes the winding of the magnet, a, and terminates in the contact-spring, c^7. The wire, 4, branches from the wire, 2, and includes the receiver, d^1, and the transmitter, d, and terminates in the contact point, a^6, with which the locking lever, a^3, makes contact when attracted by the magnet, a. The apparatus at all of the sub-

scribers' stations on the line are connected in the same manner. The main-line wires, 5 and 6, terminate respectively in the springs, g and g^1, of the spring-jack. The spring, g, normally rests on the anvil, g^2, which forms the terminal of a wire leading through the self-restoring drop, i, and the battery, k, to ground.

The operator's circuit is shown at F, l and l' being respectively the answering and calling plugs of a pair. The tips of the plugs are connected through the wire, 7, while the sleeves are similarly connected through the wire, 8; this latter wire including serially the clearing-out or supervisory signals, o and o'. The conductors, 7 and 8, include each two helices, m m' and m^2 m^3, respectively. The point between the coils, m and m', is connected to one terminal of a battery, n, while the opposite terminal of the battery is connected to the junction of the coils, m^2 and m^3. The arrangement is such that the coils, m and m^2, act inductively on the coils, m' and m^3, and *vice versa*. When a plug is inserted into a jack, therefore, the battery, n, is bridged across the line, and thus supplies current directly for operating the telephone transmitters and receivers at the substations.

The apparatus is shown in its normal or idle condition; that is, with the plugs withdrawn from the jacks and with all of the subscribers' receivers resting upon their respective switch-hooks. Suppose, now, that a subscriber at station, E, desires to be connected with some other subscriber; he removes his receiver from its hook, and the latter in rising makes contact first with the point, c^2, and immediately thereafter with the point, c^7. The making of the contact with the point, c^2, produces no result on the magnet, b, because there is no battery in circuit with the line wire, 6, with which the wire, 2, is connected. As soon, however, as the contact with c^7 is made, a current flows from the battery, k, through the coil of the drop, i, thereby actuating the shutter; thence through the contact, g^2, and spring, g, of wire, 5; thence through the magnet, a, and wire, 3, to contact, c^7, and to ground, which forms the return circuit of the battery. This current, besides actuating the shutter at the central office, causes the lever, a^3, to come in contact with the point, a^6, thus completing the circuit between the two sides of the line through the telephone apparatus proper. The lever, a^3, is allowed to rise, for the reason that the magnet, b, has not actuated its armature to pull the lever, b^4, into the path of the lever, a^3.

The operator at the central station seeing the shutter fall, inserts the plug, l, into the spring-jack, thus establishing connection with the line, and, at the same time, breaking the connection be-

tween the line wire, 5, and the drop, *i*. The operator's talking apparatus is not shown, but it is adapted to be bridged across the cord circuit, 7 and 8, in a manner well understood. It will be noticed that no induction coil is used at the subscribers' stations, the current from battery, *n*, passing directly through the transmitter and receiver in series. This circuit may be traced as follows: starting at the upper pole of the battery, *n*, the current passes through coil, m^2, wire, 8, annunciator, *o*, sleeve of plug, *l*, sleeve-spring, *g*, of the jack, line wire, 5, lever, a^3, at the subscriber's station, *E*, contact point, a^6, wire, 4, transmitter, *d*, receiver, *d'*, line wire, 6, tip spring, *g'*, at the central office, tip of the plug, *l*, wire, 7, and coil, *m*, to the other pole of the battery, *n*.

The subscriber then communicates with the central office in the ordinary manner, and is there connected with some other subscriber in the exchange by means of the plug, *l'*. Suppose, now, that while the subscriber at *E* is using his telephone, the subscriber at *E'* desires also to use the line; he removes his receiver from its hook, and as before the lever of the hook first makes contact with c^2, and later with c^7. As soon as the contact is made with c^2, however, the magnet, *b*, at that station attracts its armature and pushes the stop-controlling lever, b^4, into the path of the circuit-controlling armature, a^3. The circuit through this magnet, *b*, may not be at first apparent, but may be traced as follows: from the line wire, 6, through the magnet, *b*, at station, *E'*, to contact, c^2, and to ground; thence to the ground at station, *E*, where the receiver is also off its hook, and through the contact point, c^7, at that station and magnet, *a*, to the wire 5. Current is supplied to this circuit from battery, *n*. Since the lever, a^3, at station, E^1, cannot rise, it is impossible to complete the circuit through the telephone apparatus at that station at the point, a^6, and it is thus impossible for the subscriber at that station or at any other station to use his telephone until the subscriber at *E* has finished his conversation.

If the subscriber, E^1, had attempted to use the line after the subscriber *E* had removed his receiver from the hook, but before the operator at the central office had inserted the plug into the jack, the same state of conditions would have obtained, except that the source of current would have been from the battery, *k*; for when the subscriber at *E* removed his receiver from its hook, the battery, *k*, became connected with the wire, 6, thus making the conditions such that when the receiver at any other station was removed from its hook, the magnet, *b*, at that station would operate its lever to lock the apparatus.

The call-sending apparatus at central office and the call-receiving apparatus at the subscribers' stations are not shown, but such calling is accomplished by the use of the ordinary bridging bells.

When the subscriber at station, *E*, has finished his conversation he replaces the receiver on its hook in the ordinary manner. This breaks the connection which exists between the two sides (5 and 6) of the line, and therefore stops the flow of the current from the battery, *n*. This allows the shutter of the clearing-out drop, *o*, to fall, it having been raised automatically by this current when the connection was established. This shows the operator that a disconnection is desired. As soon as the subscriber, who is connected by the plug, l^1, hangs up his receiver, the shutter, o^1, falls in a similar manner, thus indicating to the operator that both lines are free.

This system is instructive in many ways. It not only embodies a very ingenious method for securing privacy on party lines, but also exhibits the features of automatic calling on the part of the subscriber, and of the centralized transmitter batteries already described.

Fig. 248 illustrates diagrammatically a mechanism for use on circuits practically the same as those in the system just described,

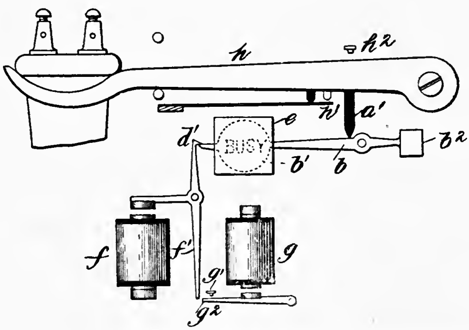


Fig. 248.—Busy Signal for Lock-out System.

with the added feature that a signal is automatically displayed for indicating to a subscriber when the line is in use at some other station. In this the stop-controlling lever, represented in this figure by f^1, carries also a catch or hook, d^1, which normally engages a lever, *b*, which carries a target marked "Busy." Assuming that the line is not busy, any subscriber who raises his receiver from the hook will obtain control of the line, as described in the previous system. The magnet,

f, however, not having current, will not release the lever, *b*, and will thus hold the target in its concealed position, even though the hard-rubber lug, a^1, on the hook-lever allows it to rise. If while the line is busy, however, a second subscriber attempts to use it, the raising of his receiver will withdraw the lug, a^1, from engagement with the lever, *b*, and, in the manner already described, the magnet, *f*, will take current. This will not only lock the lever, g^2, but will also withdraw the catch, d^1, from engagement with the lever, *b*, and allow the busy signal to rise. Thus the subscriber will not only be locked out, but will be notified of that fact by the signal. Upon the replacement of the receiver on the hook, the lug, a^1, serves to restore the busy signal, thus doing away with all magnetic resetting devices.

CHAPTER XXVI.

PARTY LINES.—"STEP BY STEP" SELECTIVE SIGNALING.

WE come now to the consideration of selective signaling on party lines, and it will be remembered that systems for accomplishing this result were divided into three distinct classes. The first of these classes includes those systems depending on step-by-step mechanisms at the subscribers' stations, controlled from the central station in such a manner as to enable the operator to pick out or select the desired station and ring its bell to the exclusion of all others on the same line. It is well to state beforehand that this branch of party-line work will be of interest mainly from a historical standpoint, and will therefore be treated in that light. There are but few lines in successful practical operation using a system of this class; but this should not detract from the interest of the subject, for there is no doubt but that the apparatus can be successfully operated on this plan, especially in view of the success of the "ticker" and other systems of telegraphy depending for their operation entirely on step-by-step movements. The use of step-by-step mechanisms in this class of telephone work has apparently from the very first offered the most plausible solution of the problem, and there are seemingly no insurmountable obstacles in the way of its being put into successful practice.

One of the very first to apply step-by-step mechanism to the partly line problem was E. N. Dickerson, Jr., as early as January, 1879. His substation mechanism is shown in Fig. 249, and the line and local circuits respectively in Figs. 250 and 251.

Referring now to Fig. 249, *B* and *C* represent two electro-magnets placed in series in the line circuit. The armature of *B* is mounted on an arbor, *h*, pivoted in the framework, *A*, as shown. This arbor carried a lever, *F*, which is moved by the armature, and by means of a pawl, *G*, steps the ratchet-wheel, *W*, around in an obvious manner. A second pawl, *P*, normally acts to prevent a backward movement of the shaft, *S*, on which the wheel, *W*, is mounted; a tendency to such backward movement being given to the wheel and shaft by the coiled spring, *v*, wound on the shaft.

The magnet, *C*, by the attraction of its armature. operates upon the arm, *M*, pivoted with the armature upon the arbor, *r*. The raising of this arm lifts both pawls out of engagement with the wheel, *W*, allowing it to be rotated by the spring until the pin, *b′*, engages the stop pin, *g*, when it is in its normal position.

Upon the end of the shaft, *S*, are two contact wheels, *c* and *d*, upon which rest four springs, *m m* and *n n*. The periphery

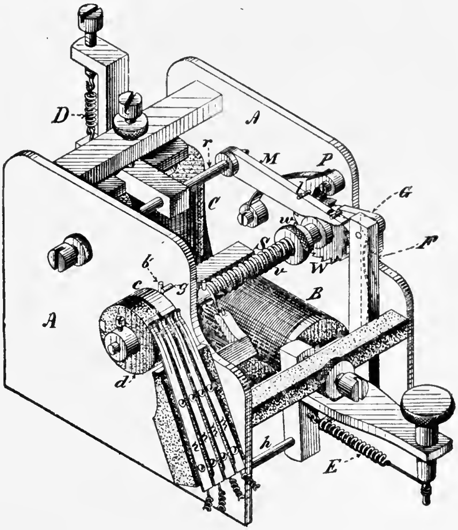


Fig. 249.—Dickerson Step-by-Step Mechanism.

of the wheel, *c*, is all of conducting material with the exception of two insulating strips, *o* and *p*, clearly shown in Fig. 250. The wheel, *d*, is of the reverse construction, all of its surface being of insulating material with the exception of the metallic contact strip, *q*, as shown in Fig. 251. In the normal position of the wheel, *c*, at each of the stations the springs, *m m*, rest upon the insulating strip, *o*. The insulating strip, *p*, on the wheel, *c*, and the conducting strip, *q*, on the wheel, *d*, are arranged at different positions on the wheels of each station, and always so that when the particular number of impulses necessary to place the apparatus at that station in operative relation to the line has been sent, the two strips, *p* and *q*, will be respectively under the springs, *m m* and *n n*.

The apparatus at the central station consists of batteries of three strengths: the weakest capable of operating only a high-resistance magnet at the central station; the next stronger capable of operating the magnets, *B*, but not the magnets, *C*;

and the third, or strongest, of sufficient strength to operate the magnets, *C*. In order to make *C* responsive to the strongest current only, the coiled spring, *D*, which controls its armature, is given a higher tension than the spring, *E*, controlling the

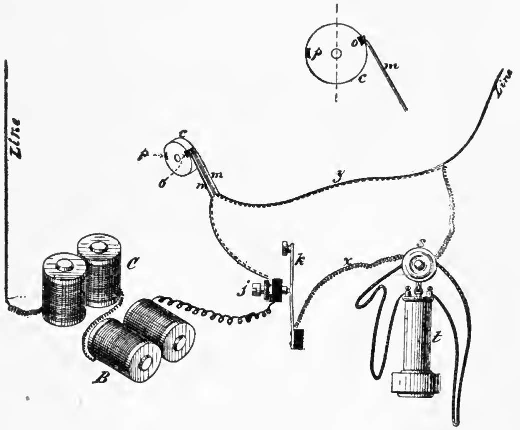


Fig. 250.—Line Circuit through Apparatus.

armature of *B*. The signal-transmitting apparatus at the central stations consists of a toothed wheel or any other device for sending a predetermined number of impulses to the line, from either

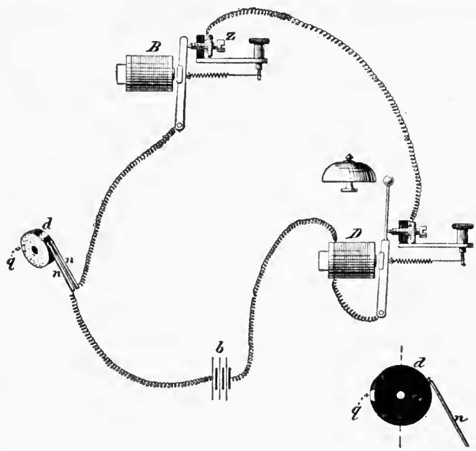


Fig. 251.—Local Circuit.

of the two stronger batteries. Normally, the weakest of the three batteries is left in line.

The normal condition of the line circuit through a station is shown in Fig. 250, where the springs, *m m*, rest on the insulating

portion of the wheel, *c*, and are therefore disconnected from each other. The receiver, *t*, is shunted out of circuit by the automatic hook-switch, *s*, upon which it hangs. In this condition, therefore, the circuit through the station is from the line through magnets, *B* and *C*, in series, thence through switch, *k*, hook-switch, *s*, and to line. The circuit is therefore complete when no one is using the line from ground at central, through the small battery and high-resistance annunciator or bell at that station, then through all the stations in series and to ground at the end station.

To signal central, a party at any station depresses the key, *k*, momentarily, thus breaking the circuit and releasing the armature of the signaling magnet at central. The party may then communicate with central by removing his telephone from its hook.

In order for the operator at central to call up any station, a number of impulses from the battery of intermediate strength is sent to line. The first one of these impulses advances all of the ratchet-wheels one step, and the springs, *m m*, therefore rest on the conducting portions of the contact wheels at all except the first station, which has the insulating strip, *p*, so arranged as to come under the springs at the first step. As a result the receivers at every station except station No. 1 are short-circuited through the by-path containing the springs, *m m*, and the disk, *c*. Suppose the station shown in Fig. 250 to be No. 5, then five impulses will bring the strip, *p*, under the springs, *m m*, when the receiver will be no longer short-circuited.

At the same time that the strip, *p*, comes under springs, *m m*, the conducting strip, *q*, on the other wheel comes under springs, *n n*, thereby completing the local circuit containing a battery, *b*, and a vibrating bell, *D*, as clearly shown in Fig. 251.

The local circuit is only closed when the armature of magnet, *B*, rests against its back stop, *Z*. This is to prevent the actuation of the bells, *D*, at the stations having a smaller number than the station desired, as it is obvious that the springs, *n n*, will wipe over the contacts, *q*, of all the stations in succession which have a smaller number than the one being called.

While this station is engaged in conversation the other stations are locked out by reason of their receivers being short-circuited. At the end of the conversation the strongest battery is thrown on the line, and the magnet, *C*, at each station causes the arm, *M*, to lift the pawls, *P* and *G*, in consequence of which all the ratchets return to their normal position.

While any good telephone man could point out many features in this system of an extremely objectionable nature, such, for instance, as the inclusion of so many magnets in series in the line, and the employment of three strengths of battery and a corresponding marginal adjustment of the magnets, the fact that such an ingenious arrangement could be devised at such an early date in the art would seem to bode exceedingly well for future development in this line.

At almost the same date George L. Anders produced a step-by-step system, depending on a somewhat different idea. All bells were left permanently in the line wire, and their hammers all actuated in unison when a pulsating current was sent over the line. A notched disk at each station prevented the bell hammer at its station from striking the bell except at such times as the notch was opposite the rod which carried the hammer. The disks were so arranged as to be stepped around by the vibrations of the bell hammers while impulses of one polarity were sent over the line. In calling a certain party a sufficient number of impulses were sent to bring the notch of the bell at the desired station into a position opposite the bell-hammer rod, after which currents of the opposite polarity were sent over the line. These latter did not actuate the stepping device, but did actuate all the bell hammers as before, and the notch in the disk of the desired station allowed that bell to sound.

Dickerson used his stepping device to control a local circuit at each station. Anders left all his circuits unaltered, and used his stepping device to control merely the length of stroke of the bell hammer.

Still another interesting example of the early art in this line is the system of Thomas D. Lockwood, designed early in 1881, which is well illustrated in Fig. 252. In this the toothed wheels, *i*, shown at the different substations are all adapted to be revolved by clockwork at exactly the same rate, so that when they are all released at once they will move with the same angular velocity until stopped. Each wheel is furnished with square teeth, corresponding in number to the stations on the circuit. These are placed at a suitable distance apart on the periphery, and in each case one tooth, *j*, of the series is composed of non-conducting material, which is inserted into the metal portion of the wheel. This non-conducting tooth, *j*, is, of course, differently placed at each station in the circuit, as shown in the drawings, where the central office wheel has its insulating tooth placed as the first tooth of the series. In station No. 2 it is the second tooth, and

so on. The material of which this tooth is formed also extends forward for a short distance toward the base of the tooth in advance, so that when the lug, *e*, of the lever, *l*, strikes the insulating

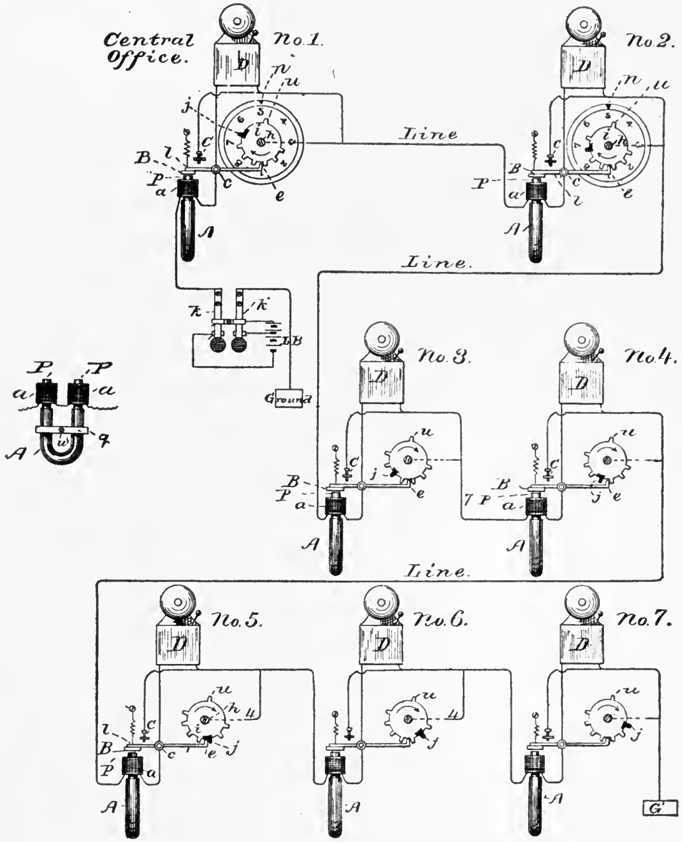


Fig. 252.—Lockwood Step-by-Step System.

tooth in any instrument it will not touch the metallic part of the wheel at any point.

Each circuit or escapement wheel is also provided with an extra tooth, *u*, set at a distance from any of the others, and when the circuit is not being used the lug, *e*, of each lever will be elevated and rest against the tooth, *u*. This tooth, *u*, affords a convenient point at which each wheel may come to rest, so that after each revolution all the wheels shall be in unison.

The release magnet, *A*, one of which is included in series in the line at each station, forms a unique feature of this system. It is shown in the small detail figure at the left of Fig. 252. *A* is a

permanent magnet of hardened steel, to the poles of which are attached two soft-iron pole-pieces, *P P*, on each of which is wound a coil, *a*. The strength of the permanent magnet may be adjusted by clamping the iron bar, *q*, at a point nearer to or farther from its pole-pieces. The strength of the magnet at each station is so adjusted that it will just hold down the armature, *B*, mounted on the retaining lever controlling the toothed wheel, *i*, at that station.

The central office is provided with a battery, *L B*, and keys, *k k'*, adapted to send a current of either polarity to the line, and also with an apparatus similar to that at each station, so that the operator may watch the positions of the wheels in their rotation.

The operation may now be readily understood. In order to start the wheels the operator depresses lever, *k'*, and holds it down. This sends to line a current of such a direction as to neutralize the polarity of each permanent magnet, *A*, so that all the levers are released, thus allowing all of the wheels to start under the influence of their clockworks. We will say that No. 5 is the station to be called. The operator watches the revolving wheel at the central station, and when the number 5 is under the index pointer, *n*, she releases the lever, knowing that the insulating tooth at station No. 5 is then under the lug, *e*, on the lever at that station. The armatures of all the magnets are thus re-attracted and all of the wheels again locked. The operator then depresses key lever, *k*, which sends a strong current of the opposite polarity to line. This does not release the levers, as it strengthens the magnets, *A*, but it does ring the bell, *D*, at station No. 5, because the shunt which normally exists around the bells at each station has been removed from bell No. 5 by virtue of the lever resting against the insulating tooth on the wheel. The bells at all the other stations are short-circuited, and, therefore, do not ring. The contacts *c* at each station are provided for short-circuiting the bells when the levers are released. To bring all the wheels again to the normal position, with the tooth, *u*, of each resting against its lever, the operator depresses the releasing key as before, and allows the wheels to rotate until the tooth, *u*, is almost reached. Each wheel is then stopped at the tooth, *u*.

Several systems depending on the same general principles as this have been devised, but none have met with success, so far as I am aware. Much trouble is experienced in keeping the wheels in synchronism, and another, and more serious difficulty, is the maintenance of the contacts in proper condition. This latter feature occurs as a fault in all step-by-step systems.

The systems so far described have all related to signaling on a single-grounded circuit with instruments in series. A similar system devised by F. B. Wood in 1888 placed all the step-by-step magnets in a controlling wire which formed a complete metallic loop, and used this circuit merely to govern the step-by-step movements which completed the desired circuits successively in a separate wire, over which the signaling was accomplished. Space will not permit of a complete description of this system, nor of one invented by Mr. John I. Sabin of the Sunset

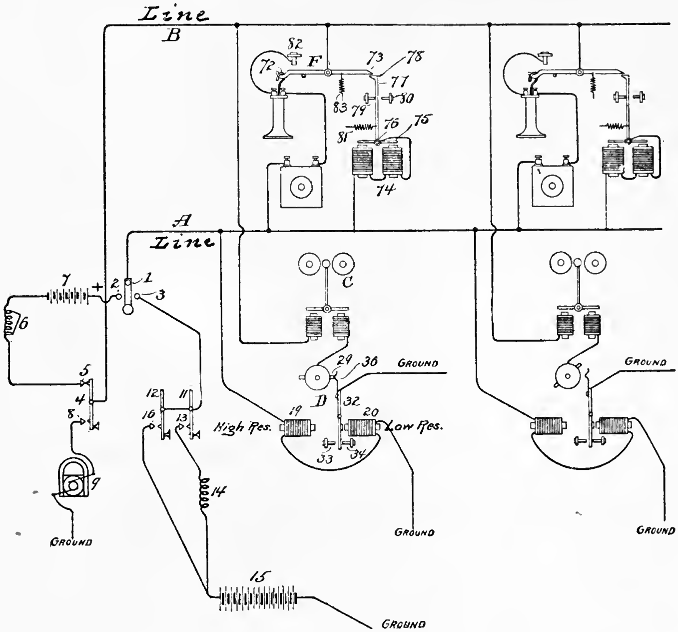


Fig. 253.—Reid & McDonnell Bridged Step-by-Step System.

Telephone Company, in San Francisco. In this latter system the magnets of the step-by-step mechanisms were placed in a third wire and used to successively close bridge circuits containing telephone instruments and call-bells at the various stations.

A more recent invention, by Messrs. R. T. Reid and J. L. McDonnell of Tacoma, Wash., is adapted for use on two wires only, and also contains lockout and automatic calling features. This system is illustrated diagrammatically in Fig. 253, and some of its mechanism shown in Fig. 254. In Fig. 253 the central office apparatus, for the purpose of clearer illustration, is shown in a greatly simplified form, the signal-transmitting ap-

paratus being represented by manual keys. The step-by-step mechanisms are shown in this figure at *D*, and are bridged between the line wire, *A*, and ground at each station. The call-bells, *C*, are of the usual polarized type, and are each contained in a normally open circuit between the line wire, *B*, and ground. This circuit at each station is adapted to be closed by the step-by-step movement.

The step-by-step mechanisms (Fig. 254) are actuated and controlled by two magnets, 19 and 20, placed in series and wound to

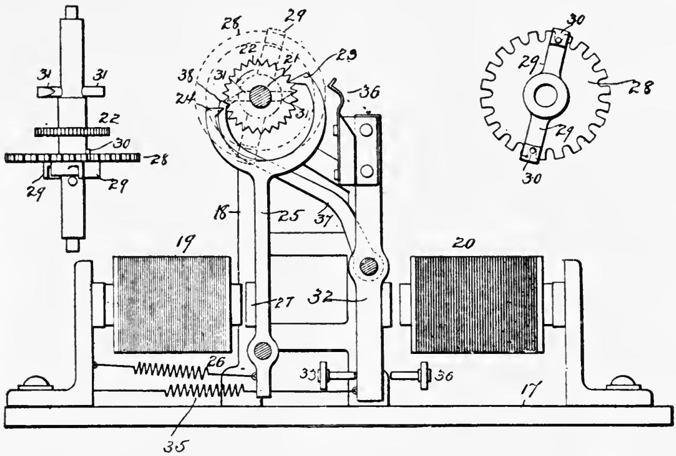


Fig. 254.—Mechanism of the Reid & McDonnell System.

respectively high and low resistances. The magnet, 19, will, therefore, operate with a comparatively smaller current than magnet, 20, owing to its greater number of turns.

Magnet, 19, by means of lever, 25, acts to step the ratchet-wheel, 22, around, this wheel carrying with it the contact arm, 29, and the stop arm, 31. These parts are mounted on the shaft as shown, the notched wheel, 28, being provided merely to secure a proper angular adjustment between the stop arms, 31, and contact arms, 29, this adjustment being different at each station. The low-resistance magnet, 20, operates a contact arm, 32, carrying a contact, 36, insulated therefrom, and also a separate arm, 37, adapted to engage the stop arms, 31, and lock the shaft.

Referring again to Fig. 253, the lock-out mechanism is represented by magnets, 74, and arms, 76. The armature is polarized so as to hold the arm, 76, either under the hook-lever, *F*, or

away from it, according to the direction of the current traversing the coils.

The operation may now be understood. To call central, the subscriber removes his receiver from its hook, thus closing a circuit at his station across the two line wires and throwing the drop, 6, at central by means of the battery, 7. This attracts the attention of the operator. The circuit so closed between the two sides, *A* and *B*, of the line includes the magnet, 74, and the current is in such a direction as to throw the lever, 77, to the right, thus allowing the hook-switch to rise and complete the telephone circuit at that station. After a plug and cord are attached to the line at the central station, a different battery of opposite polarity is connected with the line, and, should any other party remove his receiver from its hook, he will find the hook-lever locked by reason of this reversed battery.

To call any particular party, the key, 12, at central is depressed once and then released. This unlocks all of the lock arms, 31, and moves all wheels forward one step. After this the key, 11, is depressed a certain number of times. This throws a series of weak impulses on the line, which moves all the contact arms in unison. When a sufficient number of impulses have been sent, the arm, 29, at the desired station is opposite the spring, 36. The operator then depresses key, 12, and sends a strong current to line and thus operates magnets, 20. This closes the bell circuit only at the station desired, for the reason that the contact arms, 29, at the other stations are not in the proper position to make contact with spring, 36. The current from the calling generator is now thrown to line, *B*, thus operating the bell of subscriber desired. After the required signal has been sent, key 11 is again depressed a sufficient number of times to bring all stop arms into engagement with their levers, 37.

The systems described in this chapter have been chosen as representative of a large number of a similar nature. It has been thought best to give a rather complete and detailed description with intelligible diagrams of a few such systems, than to describe in a more general way a greater number.

CHAPTER XXVII.

PARTY LINES.—SELECTIVE SIGNALING BY STRENGTH AND POLARITY.

THE term "strength and polarity" is borrowed from the Patent Office nomenclature, where it is applied to that class of selective calling devices which depend for their operation on changes in the strength or in the direction of a current, or on changes in both. The idea of selective signaling by changes in the strength and polarity of a current was well-known in telegraphy before the birth of the art of telephony. The duplex and quadruplex systems of telegraphy of the present time afford the best possible demonstration of the utility and practicability of this system when properly developed. In the quadruplex, one key at each station operates to produce changes only in the strength of the current, while the other key at each station is capable of producing changes only in the direction of the current. Also at each station are two relays, one termed the "neutral relay," responsive to changes only in the current strength, being indifferent to changes in polarity, and the other termed the "polarized or polar relay," which is responsive to changes in the direction of the current only, being indifferent as to its strength. The arrangement is such that the key at one station governing the strength of current will operate only the neutral relay at the other station, while the key governing the direction of current will operate only the polarized relay at the other station. This system, therefore, not only admits of selective signals being sent one at a time, but also allows four to be transmitted simultaneously over a single grounded circuit, two in one direction and two in the other.

The problem is somewhat different in telephone work, but the same principles are involved, and the success of the quadruplex telegraph demonstates beyond question that the strength and polarity system can be made thoroughly practical in telephony. At present, nearly all of the party lines successfully using selective signaling are operated on this general plan.

Among the first to attack the problem from this standpoint was George L. Anders, who in 1879 produced a two-party line system, having the call-bells at the two stations polarized oppo-

sitely, and included serially in the line wire. Currents in a positive direction would therefore operate the bell at one station, and those in a negative direction that at the other. The call bell was arranged with two armatures, one polarized and one neutral, the latter serving to operate the bell striker, and the former serving simply as a lock for the striking armature. The bell would operate only when the current was of proper direction to cause the magnet to remove the locking armature from the path of the striking armature. The operator at the central station used a double lever key to send either positive or

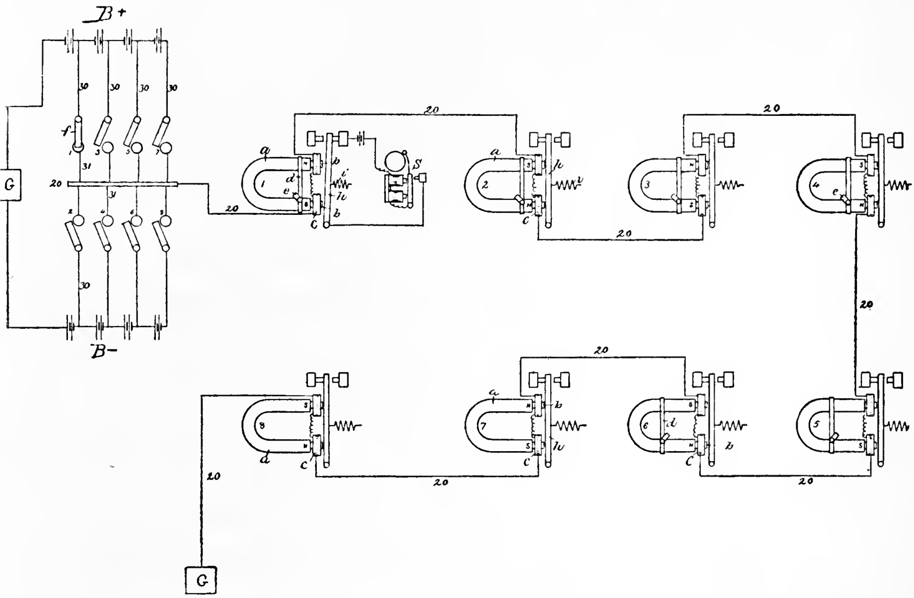


Fig. 255.—Anders System.

negative calling currents to line. This was the forerunner of several more successful plans recently devised.

The system shown in Fig. 255 is interesting as being one of the early attempts to utilize changes of both strength and polarity. It is typical of many of the early failures in this line of work, and is not here described because of any practical ideas it contains.

Eight stations are connected in series in the line, which is adapted to be grounded at central through the various keys and batteries as shown. Each of the controlling magnets consists of a permanent horseshoe magnet carrying soft-iron pole-pieces and bobbins. The armature of each magnet is normally attracted by

the permanent magnetism, and thus holds open a local circuit, shown only at the first station, containing a battery and bell at each station. The magnets at stations 1 and 2 exert an equal pull on their armatures, but are of opposite polarity, and likewise the two magnets in each other pair of stations are of equal strength, but of opposite polarity. The strength of the magnets is, however, different for each successive pair of stations—those at stations 1 and 2 being the weakest, and those at stations 7 and 8 the strongest. Four different strengths of current of either polarity may be sent to line from central by the closure of the various switches. The magnet at any given station is supposed to release its armature only when a current of the proper strength and direction is sent over the line to exactly neutralize its permanent magnet. Thus, if it is desired to call station 1, switch lever 1 at central is closed. This sends a positive current from one set of cells over the line which is of the proper strength and direction to neutralize the pull of the magnet at station 1. This magnet will therefore release its armature. The armature at station 2 will not be released, because the current is in the wrong direction, and therefore strengthens the pull of the magnet. The armatures at the other stations will not be released, because the current is not strong enough. In calling, say station 8, a strong negative current would be employed. This would more than neutralize the magnets of stations 2, 4, and 6, giving them an opposite polarity, and thus still attracting their armatures. All such systems, depending for their action upon close marginal adjustment of the strengths of magnets, have proven failures in practice, because of the varying of conditions assumed to be constant.

Coming now to the more practical systems, one due to Sabin & Hampton, and used to some extent on the Pacific Coast, will be considered. This is not properly a strength and polarity system, but is described in this place because it contains several ideas upon which later systems have been based. The idea upon which this is based is that three circuits may be obtained from the two wires of a metallic circuit by using the two wires for one circuit, one of the wires and the ground return for another, and the other wire and ground for the third. In Fig. 256 two party lines of three stations each are shown connected through a cord circuit and the jacks and plugs of a switch-board at the central office. The circuits of one station are shown in the small detached portion of this figure. Between the two limbs of the metallic circuit are included the talking apparatus, composed of

the transmitter, t, and receiver, r, associated with the induction coil, battery, and switch-hook in the ordinary manner. The talking circuits at all of the stations are the same as this, but are represented merely by a circle in each station. The bell, b, of subscriber *A* is included with a condenser in a bridge circuit between the two sides of the line, the bell, b, of subscriber *B* is included in a branch between the side, a', of the line and ground, while the bell, b, of subscriber *C* is similarly included between

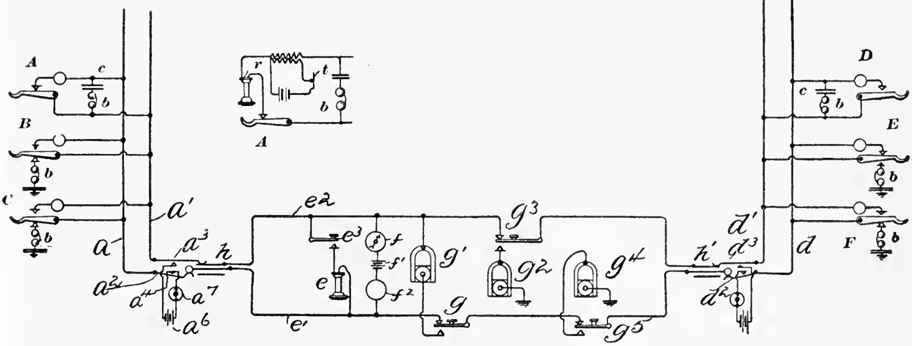


Fig. 256.—Sabin & Hampton Three-Station Line.

the other side, a, of the line and ground. The bells of stations *D*, *E*, and *F*, on line, $d\ d'$, are similarly arranged.

The limbs, $a\ a'$, of the metallic circuit extend to the line springs, $a^2\ a^3$, of a spring-jack on the switch-board, which normally rest against the contact anvils, $a^4\ a^5$, between which are included the battery, a^6, and indicator or annunciator, a^7.

The operator's telephone set, e, is included in a normally open bridge between the tip and sleeve strands, $e'\ e^2$, of the cord, a key, e^3, being provided for bridging the telephone into circuit. A clearing-out indicator, f, and battery, f', are included in a bridge between the two strands, a balancing coil, f^2, being also located in said bridge. By means of a key, g, a generator, g', may be bridged between the strands, e' and e^2, the generator, g^2, by means of a key, g^3, may be connected between the sleeve strand, e^2, and ground, while the generator, g^4, by means of the key, g^5, may be similarly connected between the tip strand, e', and ground.

Suppose subscriber *A* desires to converse with subscriber *D*. He removes his telephone from its hook, thus completing the circuit of battery, a^6, through indicator, a^7, and thus calling the attention of the operator, who inserts answering plug, h, in the

spring-jack, thereby cutting out battery, a^6, and indicator, a^7. The operator then depresses the key, e^3, thus bridging her telephone into circuit and receives the number of the called subscriber *D*. She then inserts calling plug, h', in the spring jack in which the limbs, $d\ d'$, terminate, and depresses key, g, thus sending a calling current from the generator, g', over the metallic circuit to actuate the bell, b, at station *D*. Subscriber *D* removes his telephone from its hook and *A* and *D* are connected for conversation.

Had *A* desired connection with *F* instead of *D*, the operator would have depressed key, g^5, thus ringing the bell, b, at station *F*, over a circuit formed by the line wire, d, with ground return.

The condensers, c, at stations *A* and *D* are for the purpose of preventing the steady current from battery, a^6, from leaking through the bridges in which the bells, b, at those stations are placed. These condensers form a break in these bridges through which an unvarying current cannot pass, but they allow the alternating currents from the calling generator to act inductively through them to operate the bells as though they were not present.

Where three stations are thus operated on a metallic circuit, much trouble occurs, due to the fact that the two bells on a line at the stations which are not being called are always in series in a circuit which forms a shunt to the bell at the station which is to be called. Thus if a generator current is sent over the metallic circuit to call station *A*, a part of this current will leak from limb, a', through bell, b, at station *B* to ground, thence to ground at station *C* and through the bell, b, at that station to the other limb, a, of the line. This bridge circuit has about twice the resistance of the bridge at *A* (disregarding the condenser), and this fact must be depended upon to prevent the bells at *B* and *C* from ringing. The same conditions exist in ringing either of the other bells, and this difficulty has rendered the use of three stations on a line, according to this method, impracticable save in rare cases, as it is very difficult to so adjust the bells that they will respond only at the proper times. Two stations on a line, arranged as at *B* and *C*, may, however, and often do, give good service. On long lines, however, there is sometimes enough induction between the two wires of the metallic circuit to cause both bells to ring when only one is intended to respond.

A very successful four-station party-line system devised by Mr. Angus S. Hibbard is shown in Fig. 257. In this system, as in several others, the idea first used by Anders, of placing two

oppositely polarized bells on a single line, has been combined with that of Sabin & Hampton, just described, of ringing over different circuits formed by using the separate limits of the line with a ground return.

At stations *A* and *B* polarized bells, *d* and *d'*, are connected between the limb, *a*, of the line and ground. The bell at *A* is so polarized as to be operated only by currents sent over the limb, *a*, in one direction, while the bell at *B* will respond for a

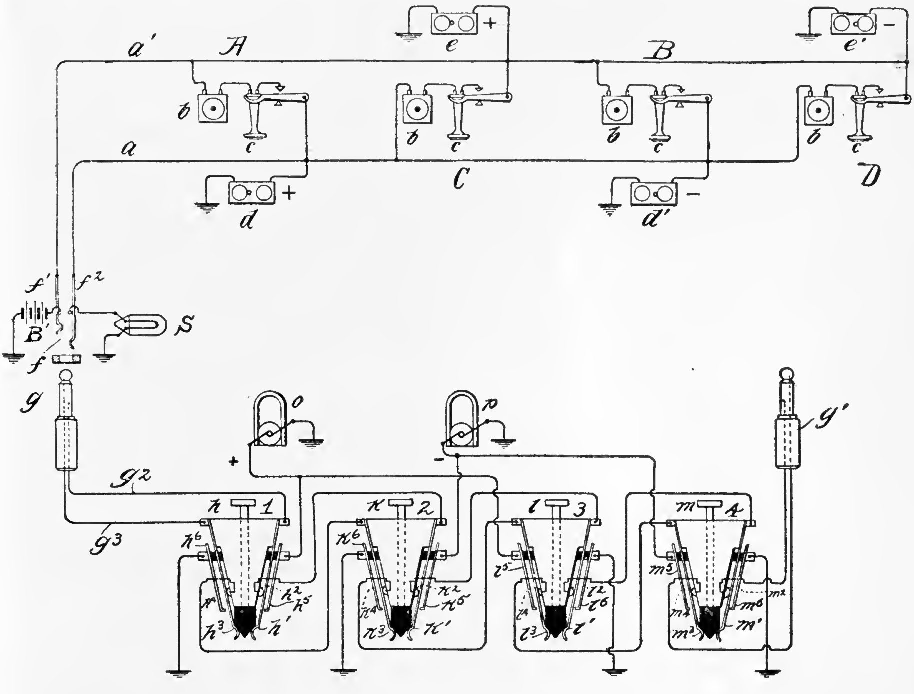


Fig. 257.—Hibbard Four-Station Line.

similar reason only to currents in the same limb in the opposite direction. In like manner, the bells, *e* and *e'*, at stations *C* and *D* are oppositely polarized and connected between the limb, *a'*, and ground, so that bell, *e*, will respond to current sent over line, *a'*, in one direction, while the other bell, *e'*, will respond to current over the same wire in the opposite direction. Thus, any one of the four stations may be called alone by sending the current in the proper direction over one of the two wires.

The line terminates at the central station in a spring-jack, *f*, composed of line springs, *f'* and f^2, normally resting against anvils, connected respectively to a battery, *B'*, and signal indicator,

S, in substantially the same manner as in the Sabin & Hampton system. In this case, however, the signal indicator is an incandescent lamp adapted to be lighted by current from the battery, B', when the receiver at any station on the line is removed from its hook.

Four ringing keys, 1, 2, 3, and 4, are associated with the plugs, g and g', in such manner as to enable the operator to connect the terminal of either of two grounded generators, o and p, with either the tip or sleeve strand of the cord, and therefore with either side, a' or a, of the line into the jack of which plug, g, is inserted. The generators, o and p, have opposite poles grounded, and we will say generator, o, is adapted to send positive impulses to line, and generator, p, negative ones.

When it is desired to ring the bell at station *A* key No. 1 is depressed, thus closing the circuit of generator, o, through contact, h^5, spring, h', sleeve-strand, g^2, plug, g, spring, f^2, limb, a, bell, d, to ground and back to the generator. A portion of the current also passes through bell, d', to ground, but as this bell is polarized to respond only to negative currents it remains irresponsive. Should it be desired to ring the bell at substation *B*, key No. 2 is depressed, thus sending a negative current from generator, p, to line, a, through k^5, k', h^2, h', strand, g^2, and by the same path as before through bells, d and d', to ground. Only bell, d', will operate, because d is responsive only to positive currents. In like manner stations *C* and *D* may be called by pressing keys No. 3, or No. 4.

When the key No. 1, for instance, is depressed to connect the generator, o, in circuit with the limb, a, and ring the bell, d, the spring, h^3, is brought into engagement with grounded contact, h^6, thus grounding the strand, g^3, and the limb, a', and preventing the accidental ringing of the bell, e, should, for instance, one of the telephone-receivers be removed from its hook and a path thus provided to the limb, a'. The current thus finds a short path to ground over the limb, a', strand, g^3, and grounded spring, h^6, and sufficient current will, therefore, not pass through the bell, e, to ring it.

Instead of providing four keys in each cord set, a single set of keys is usually provided, adapted to be connected by a suitable switch with any particular pair of cord conductors that may be for the time in use.

This system with slight modifications is used in a number of Bell exchanges and apparently is a success. The practice of putting the lamp signal directly in the line circuit has, however,

not proven very satisfactory, even in cases where a separate metallic circuit serves each subscriber. Accidental crosses or grounds on the line expose the lamps to higher voltages than intended, thus frequently causing burn-outs. On party lines another difficulty arises, due to the difference in the resistance of the circuit when closed at the different stations, owing to the resistance of the line wire between the stations. Obviously the circuit formed by removing the receiver at *A* is of less resistance and will therefore expose the lamp to a greater voltage than that

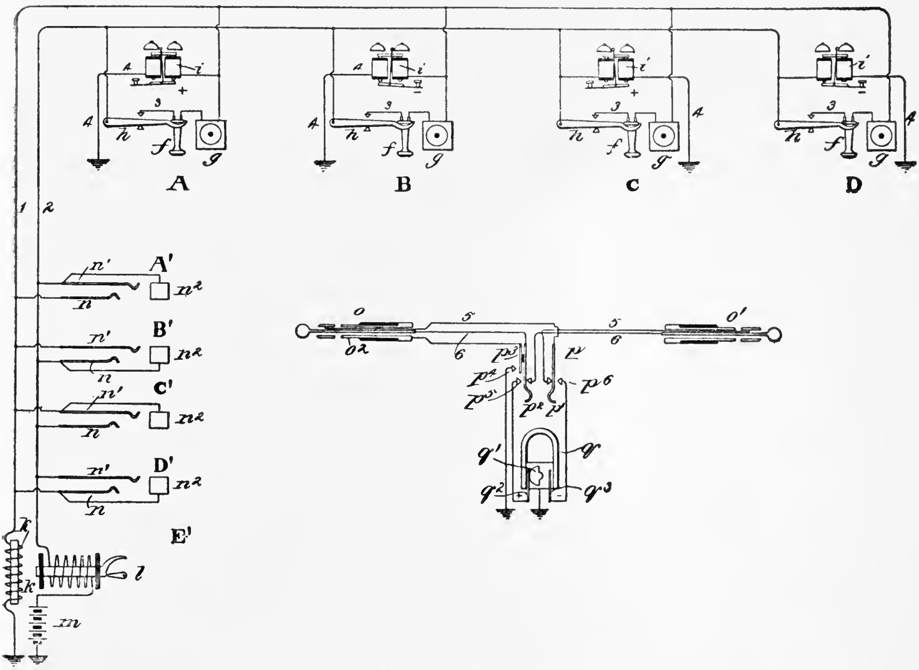


Fig. 258.—McBerty Four-Station Line.

formed by removing the receiver at *D*. This, however, could be compensated for by winding the receivers of the nearer stations higher than those at the farther, or by inserting compensating resistance coils, but such arrangements are undesirable.

Another system using exactly the same method of selective signaling, but employing a very ingenious arrangement of apparatus for carrying it out, is one devised by Mr. F. R. McBerty of the Western Electric Company. This is shown in Fig. 258. The bells at each of the stations and also the talking apparatus are arranged with respect to the two wires of the

metallic circuit in precisely the same way as in Hibbard's system. As a safeguard to prevent the bells ringing by the wrong direction of current, a light spring acts on the pivoted armature of each to retain the armature normally in the position toward which it would be attracted by a current in a direction not intended to operate the bell. The operation of signaling central is identical with that already explained.

In connection with the line conductors, 1 2, are four spring-jacks, A', B', C', and D'. Each of these has a short line spring, n, a long spring, n', and a tubular thimble, n^2. The connection of these springs and thimbles to the conductors of the line is different in the case of each jack, as examination will readily show.

The switch-board is provided with the usual plugs, o o', forming the terminals of a plug-circuit, 5 6, which includes a calling key, p. This key, p, in addition to the pair of switch springs, p' p^2, and their normal and alternate contact anvils, has a spring, p^3, which is adapted to register with an anvil, p^4, when the spring is thrust outward. The spring, p^3, constitutes the terminal of a contact piece, o^2, of the calling plug, o, which is constructed to register with the ring, n^2, of a spring-jack into which the plug may be inserted. The anvils, p^5 p^6, of springs, p' and p^2, constitute the terminals of a generator, q, of alternating currents. This generator is due to Scribner, and is of peculiar construction. It has an armature of the ordinary type, one of whose terminals is grounded permanently, and the other of whose terminals is led to a semi-cylindrical commutator, q', which rotates between two contact springs, q^2 and q^3. These springs are so placed with relation to the point at which the direction of the current in the armature is changed that spring, q^2, receives in each revolution a pulsation of positively directed current, and the spring, q^3, during the other half of the revolution a negatively directed pulsation. The operation of the key, p, therefore always connects the positive spring of the generator with the tip strand, 6, the negative spring with the sleeve strand, 5, and at the same time connects the plug contact, o^2, with the ground. The arrangements of the jacks with respect to the line wires are such that the mere insertion of the plug, o, in any jack will establish the proper relations between the generator and the line, to operate the bell at the corresponding station upon the depression of key, p. Thus suppose the operator wishes to call station A. She inserts the plug in jack, A', of that line, and depresses key, p. A pulsatory current in a positive direction will now flow from the spring, q^2, through the contact points, p^5 p^2, thence through conductor, 6, of the plug

circuit to line conductor, 1, and thence through branch 4 and bell, *i*, at station *A* to ground. The bell will be operated by this current. The bell at station *B* will also receive part of this current, but not be operated on account of its polarity. A pulsatory current, whose pulsations occur in the intermissions of current through spring, q^2, and of opposite direction, will flow out from spring, q^3, through conductor, 5, of the plug circuit to spring, n'; but from this point a short circuit is provided through the thimble, n^2, to the contact-piece, o^2, of the plug, and thence through the contacts, p^3 p^4, of the key to earth. Hence no signaling current will reach the line conductor, 2, and the operation of the bell at station *D* will be prevented.

By tracing out the circuits through the other jacks it will be found that in each case the spring-jack into which the plug is inserted determines which of the signals connected with that line shall be operated.

When the operator has made a connection with any spring-jack, and has operated the signal at the corresponding station, the presence of the plug, *o*, in that spring-jack indicates to her, during the existence of the connection, the station which has been signaled. If it should be necessary to signal the same station again, she does not have to remember which party on that line has been signaled, for she may be sure of again calling the same one by merely pressing the key, *p*. If it should be necessary to make any charge, as in the case of a toll connection, the identity of the station signaled is ascertained by the presence of the connecting plug in the corresponding spring-jack.

A system devised by Mr. W. W. Dean, now of the Western Electric Company, and based on the same principles as those of Hibbard and McBerty, but adapted for eight stations instead of four, as in each of those systems, is shown in Fig. 259. The Hibbard and McBerty systems may be called polarity systems only, the strength of the current playing no part in the selection of the particular station to be called. The Dean system, however, is one of the few examples of a true strength and polarity system—that is, one depending on both the polarity and the strength of the current. In this system four stations are associated with each branch or limb of a metallic-circuit line. The two call-bells on each of the limbs at the four stations farthest away from the central office are oppositely polarized and bridged between the respective line wires and ground, in exactly the same manner as in the four-party lines of Hibbard and McBerty. In fact, the four stations at the farthest end of the line from the

central office may be considered, so far as the signaling is concerned, as the counterpart of those systems already described. The two call-bells on each limb at the four stations nearest the central office are low-wound and placed in the line wires. They are also oppositely polarized. A relay is provided for each limb, each having a high-resistance magnet and being bridged to ground at a point between the two high-resistance bells and the two low-resistance bells on each limb. Each of these relays,

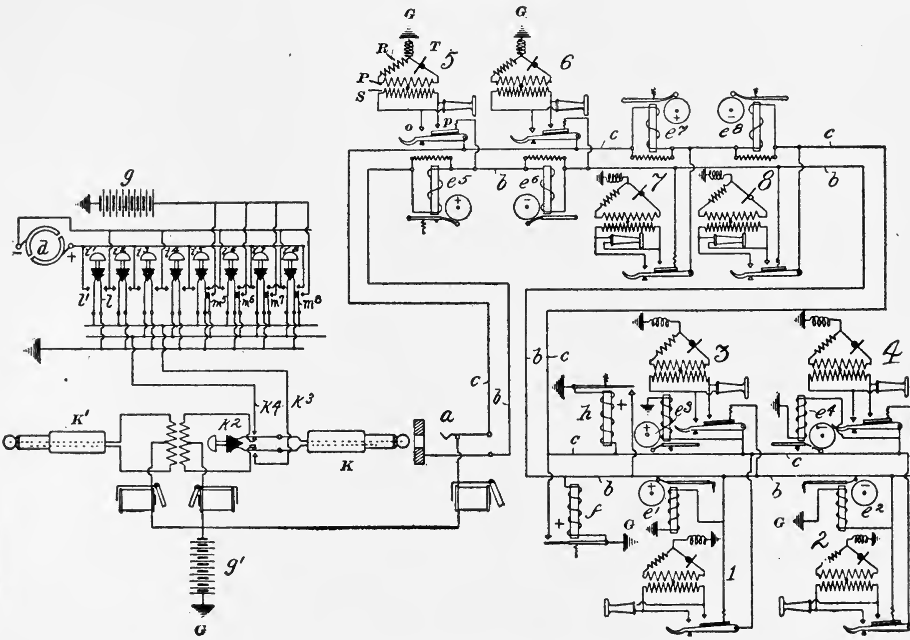


Fig. 259.—Dean Eight-Station Line.

when operated, serves to ground the opposite limb of the line at that point.

The principle of operation of this system is that a current adapted to ring one of the high-resistance bridge bells at one of the four more remote stations will not be of sufficient strength, owing to the high resistance of the circuit, to ring one of the low-wound series bells at the four nearer stations. Therefore, under ordinary circumstances any one of the four stations having bridged bells may be called by exactly the same method as those described in connection with the Hibbard system. When, however, one of the four nearer stations is to be called, the relay on the limb to which the bell of that station is not attached, is

actuated. This grounds the limb of the line on which the desired bell is placed and therefore cuts out the high-resistance bells on the farther end of the line. A current of proper polarity is then sent over this limb, which current is now capable of ringing the desired bell on account of the low resistance encountered. This method of doubling up the capacity of a line by such simple means is characteristic of Mr. Dean's work in general.

A consideration of Fig. 259 will make clearer the operation and details of this system. 1, 2, 3, 4, 5, 6, 7, and 8 represent the subscribers' stations on a metallic circuit, composed of wires, *b* and *c*. *K* and K^1 represent the calling and answering plugs respectively at the central office; *g* is a battery or other direct-current generator, while *d* is a generator from which pulsating currents of either positive or negative polarity may be taken as desired; l^1, l^2, l^3, etc., are keys adapted to send positive or negative pulsating currents, or direct current from the battery, *g*, over either side of the metallic circuit to which the plug, *K*, is connected by being inserted in the spring-jack, *a*.

At stations 1 and 2 the positively and negatively polarized high-resistance bells, e^1 and e^2, are bridged between the limb, *b*, of the line and ground. A current from the negative side of the generator, if sent over the limb, *b*, will therefore actuate bell, e^2, e^1 not being actuated on account of its not being responsive to currents in that direction. This current will also traverse the ringer coils, e^5 and e^6, at stations 5 and 6, but will not operate them because too feeble, these bells being wound to a rather low resistance and also shunted by a dead resistance in order to further reduce their sensibility. Suppose, however, station 6 is to be called; the operator first sends a direct current from the battery, *g*, over the line wire, *c*, which current operates the relay, *h*, and causes it to hold its contact points closed. This, as will be seen, grounds the limb, *b*, at a point between the first high-resistance bell and the last low-resistance bell on that limb. A pulsating current from the negative side of the generator is then sent over the limb, *b*, which passes through bells, e^5 and e^6, and to ground at the relay, *h*. Inasmuch as this current does not encounter the high resistance of the bell magnets beyond, it has sufficient strength to operate bell, e^6, but does not operate bell, e^5, because it is of the wrong polarity. The selection of any station whose bell is connected with the other limb, *c*, of the line is performed in exactly the same manner. The ringing keys, l^1 to l^8, inclusive, are so arranged that pressure upon any one of them will send the proper current or currents to line. For

instance, depressing l^1 will ground the negative side of the generator and connect the positive side with the limb, *b*, which will therefore call station No. 1. If one of the buttons designed to ring the four nearer stations is depressed, it will, besides sending the proper pulsating current to line, also send the direct current from battery, *g*, to the opposite line, in order to operate the relay, *f* or *h*, as the case may be.

Although not forming a part of the selective signaling system, the arrangement for accomplishing the centralization of all transmitter batteries will be described, because it is of much general interest. The battery, g', is connected to the centers of both sides of an induction coil placed in the cord circuit. Suppose the receiver of station 5 to be removed from its hook, the current from g' will proceed to the center of the induction coil in the cord circuit, where it will divide, passing in parallel over the two wires, *b* and *c*, of the line. It will then pass to the contact points, *o* and *p*, of the switch-hook, and to the center point of the secondary of the induction coil at station 5. Here it will again divide, one-half passing through the transmitter, *T*, and the other half through the resistance coil, *R*, to the ground at *G*. The coil, *R*, has the same resistance as the transmitter, *T*, under normal conditions. When, however, the resistance of the transmitter, *T*, is lower, the greater portion of the current will flow through it and a smaller portion through *R*, giving the equivalent of a current from left to right in the primary coil, *P*, of the induction coil. This will induce a current in the ordinary manner in the secondary, which will pass over the line and affect any other receiver connected with the circuit. An increase in the resistance of the transmitter, *T*, will produce an opposite result, thus causing an induced current in the opposite direction to flow in the line. Thus while the current from battery, g', produces no effect on the apparatus in the line under ordinary circumstances, it supplies the current for the local circuit of a station which, when operated upon by the transmitter, affects inductively the secondary circuit connected with the line.

A system which is being put into practical operation, and is apparently meeting with much success, was recently devised by Messrs. Barrett, Whittemore and Craft. It depends for its operation on the sending of currents of either polarity, or different combinations of currents, over either or both of two line wires in combination with each other or with the ground. Thus calling one line wire *A*, and the other *B*, and representing the ground by *G*, it is evident that without using wire, *B*, at all, a current could be sent

over wire, *A*, with a ground return in either direction, thus giving means for two selective signals. Similarly leaving *A* out of the question, a current of either direction could be sent over *B*, with a ground return, thus providing for two other selective signals. So far the combinations are identical with those of Hibbard. A current may also be sent in either direction over the metallic circuit formed by *A* and *B*, thus providing for two other signals; and lastly, by using *A* and *B* in multiple, currents could be sent in either direction, using a ground return, thus affording means for two more signals, or eight in all. Two other combinations might be obtained by sending currents in either direction over wire, *A*, and using wire, *B*, and the ground in multiple, as a return; and similarly two others by using *B* for one side of the circuit with the wire, *A*, and ground in multiple

CURRENT COMBINATIONS.

	Line A.	Line B.	Ground.
1	+	o	—
2	—	o	+
3	o	+	—
4	o	—	+
5	+	—	o
6	—	+	o
7	+	+	—
8	—	—	+

for a return. These latter combinations, however, have been found to introduce undesirable features, as will be understood later on. The eight desirable current combinations may be tabulated as in the table above.

In this table the plus and minus signs indicate which pole of the calling battery at central is connected to either line wire or ground. Thus, in the first combination, the positive pole is connected with line, *A*, the negative with the ground in order to utilize the earth return. Line, *B*, in this combination, is not used at all.

Fig. 260 shows diagrammatically such an arrangement of apparatus at eight stations that the call-bell, *D*, at each station will be actuated only when the one particular set of current combinations is sent over the line. *A* and *B* represent two line wires extending from a central station, *C*, to a number of substations, *S*, S^2, S^3, etc. At each of the substations are two relays, *R* and R^2, placed in earth branches, *m* and *q*, from the two line

wires, *A* and *B*, respectively. These two branches are united at *e*, and connected with the ground at *G*. The signal bell, *D*, is connected with the local battery, *s*, in a circuit, the continuity of which is controlled by each of the relays, *R* and R^2. Unless the armatures, 13, of both relays rest against their back stops, 12, the local circuit containing the bell will be opened at one or two points. The relays of each station differ in some way, either in construction or arrangement, from those of all other stations. Thus at station, *S*, the main conductor, *A*, is branched through a

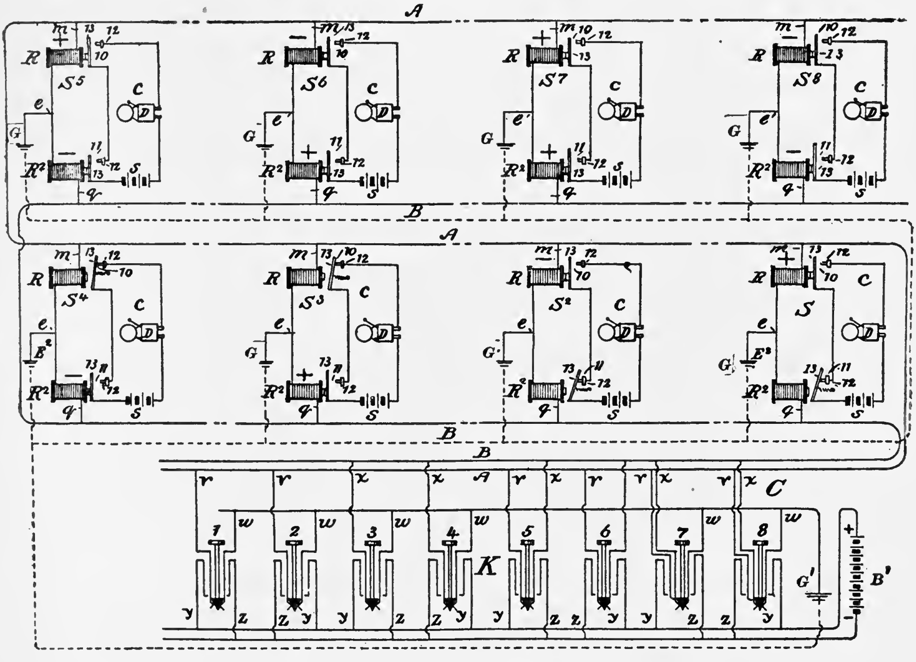


Fig. 260.—Simplified Barrett-Whittemore-Craft System.

polarized relay made responsive to positive currents from the central office, and the main conductor, *B*, through a neutral relay, R^2, adapted to respond to currents of either direction from the central office. It is thus obvious that if a positive current is sent over wire, *A*, without sending any current whatever over *B*, the bell at station, *S*, will be operated because the positive current will cause the relay, *R*, to release its armature, while the armature of relay, R^2, is already released. Thus, both contacts, 10 and 11, will be closed and the bell circuit complete. Station, S^2, also has a neutral relay on wire, *B*, and a negatively polarized relay on wire, *A*. The third and fourth stations, S^3,

and S^4, each have a neutral relay on wire, *A*, and a positively or negatively polarized relay on wire, *B*. The fifth station, S^5, has two polarized relays, one adapted to respond to positive currents and attached to wire, *A*, and the other to negative currents and attached to wire, *B*. The sixth station, S^6, also has oppositely polarized relays, but their connection with the line is the reverse of that in station, S^5. The seventh station, S^7, has two positive relays and the eighth station, *S* , two negative relays, one in each case being bridged between each limb of the line and ground.

Reference to the table of current combinations will show, in connection with Fig. 260, that the sending of any particular combination to line will operate the relays of the station bearing the corresponding number in such manner as to close the local circuit at that station. Further consideration will also show that no combination will so operate the relays at more than one station.

At the central station, *B′*, is a generator of calling current, and *G′*, an earth connection complementary to the earth connections, *G*, at the substations. *K* is a group of signaling keys, each corresponding with one substation appliance, and when any particular key is pressed it sends the proper current combination to line so that the relays at the particular substation represented by it will co-operate to close the local circuit and give the signal there; but at the other stations no such effect will take place. Hence, to give a signal at any desired substation, it is only necessary to operate the particular key representing such station. To accomplish this, branch terminals are brought from the line conductors, *A* and *B*, from the ground connection, *G′*, and from the positive and negative poles of the battery to the various terminals on the signaling keys. The arrangement of the terminal contacts in each key is different, the differences corresponding with those of the substation relay arrangement.

To illustrate: in key No. 1 the contacts are so disposed that its operation will connect conductor, *A*, with the positive pole of the battery, *B′*, at contacts, *v* and *y*, the minus pole of the generator with the earth terminal-contacts, *z* and *w*, and will leave conductor, *B*, disconnected. By this means a positive current is sent over line, *A*, and is distributed through all the *A* relays at all of the substations in parallel, finding return through the earth branches; but as no current is transmitted over line conductor, *B*, all of the eight *B* relays will remain unaffected. Under these conditions relay, *R*, at station, *S*, will close point, 10, of its local circuit, and the point, 11, being already closed by the

armature of relay, R^2, the normal position of which has not been changed, the local circuit, c, of station, S, will be closed and the bell at this station will be rung. Station, S^2, will not be signaled, because plus currents have no effect on its polar relay, R. Station, S^3, is not signaled, because the effect of the plus current on main, A, is to attract the armature of neutral relay, R, and thus open the local circuit, which is already open at point, 11. Station, S^4, receives no signal for the same reason. Station, S^5, is not signaled, because, though the positively polarized relay on A closes the open point, 10, of its local circuit, the said circuit remains open at 11, there being no current on B; station, S^6, because neither relay is acted upon, R being of minus polarity and R^2 having no current; station, S^7, because R alone is operated, and station, S^8, because both relays are of minus polarity.

In applying the principles already pointed out to a practical multiple-station circuit, it is desirable to reserve two of the current combinations for the operation of locking devices common to all stations.

The seventh and eighth combinations in the foregoing table have been found most convenient for this purpose. The seventh, that is, the positive current over both conductors, A and B, in parallel, is used for locking the telephone apparatus at all stations, and a negative current over both lines for unlocking the apparatus. Six combinations are thus left for signaling.

The locking device and a visual busy signal are shown in association with complete telephone equipments at two stations in Fig. 261. In these an additional electromagnetic apparatus, R^3, is shown in circuit with the relays, R and R^2, at each substation, half of its winding being in the earth branch, m, of the relay, R, and half in the branch, q, of the relay, R^2.

Two electromagnetic helices, a and b, have the ends of their cores joined by soft-iron yoke-pieces to form the instrument, R^3. Two soft-iron polar extensions, h and f, project inwardly from the yoke-pieces as shown. A polarized bar armature, j, pivoted at j^2, has one of its poles projecting between the pole-pieces, h and f, and adapted to move to one side or the other under the influences of said pole-pieces. If current is passed through coil, a, only, the magnetic polarity developed will be short-circuited through the yoke-pieces and the core of coil, b, so that very little strength will be manifested in the pole-pieces, h and f; if current be applied to the coil, b, only, the magnetic polarity will be similarly short-circuited, and, again, little effect will be manifested in the pole-pieces. Again, if current be applied to both coils, a and

b, so as to act in a complementary direction, the yoke-pieces will satisfy the magnetic flux with very little polarity in, *h* and *f*; but if current be applied to coils, *a* and *b*, in inductively opposed direction, as will be the case when the seventh and eighth combinations are transmitted, consequent poles of full strength and

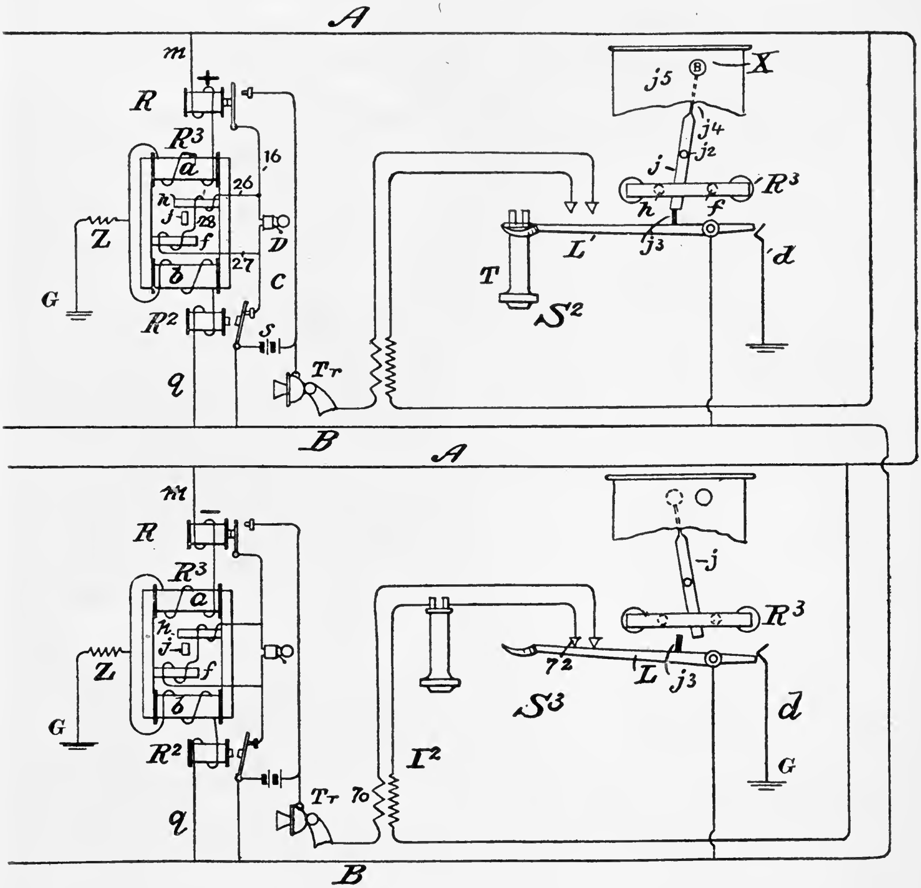


Fig. 261.—Lock-out Mechanism.

opposite polarity will be formed at *h* and *f*. The polarized lever, *j*, is, therefore, actuated by the seventh and eighth current combinations and remains unaffected by all others.

As shown at the right of Fig. 261, the lever, *j*, serves not only as a lockout device, but also as a busy signal. The apparatus is shown in its locked or busy position at station, S^2, of this figure and in its unlocked or free position in station, S^3. When the lower portion of the lever is moved to the left it forms a stop to

lug, j^3, on the hook-switch, z, and thus prevents the latter from rising should the receiver be removed from the hook. At the same time the small target, B, on the other end of the lever is displayed through a hole in the box, thus showing the party at that station that the line is busy. When in its other position the busy signal is not displayed and the hook-switch is free to rise.

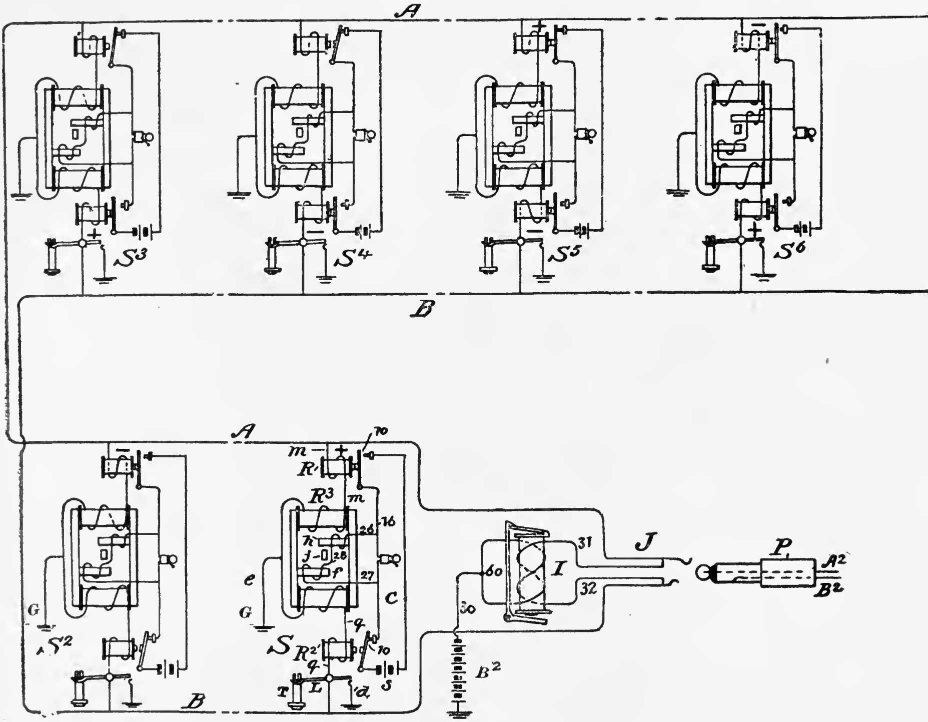


Fig. 262.—Circuits of Six-Station B. W. C. System.

When the operator at central presses the locking key, say key No. 7, all of the locking levers on the line, including that of the party to be called, will be actuated. In order that the party being called may not be thus locked out, the windings, 27 and 28, are provided around the polar extensions, h and f, on each instrument. This winding has no function except at the station being called. In that station part of the current from the local circuit, which is closed only at that station by the action of the relays, finds path through this winding, and the magnetism so developed serves to unlock the mechanism and to allow the party at that station to use his instrument.

In Fig. 262 is shown a six-party line, the equipment at each station being of a similar character to that shown in Fig. 261, but simplified for the purpose of clearer illustration. The two sides of the line terminate in the line springs of a spring-jack, *J*, which springs normally rest on anvils connected to the windings, 31 and 32, of a differentially wound switch-board drop. These two windings pass around the core of the drop magnet in opposite directions, after which they unite at the point, 60, and pass to ground through a battery, B^2. The relative direction of the windings on the drop is such that the current from this battery circulates around the core in opposite directions, and thus does not affect the drop. It then divides equally between the two main conductors, *A* and *B*, and finally returns by the ground connections, *G*, at each of the several stations. The current thus flowing to the two conductors from the battery, B^2, is in a negative direction, and thus tends to maintain the apparatus at the several stations in its unlocked condition.

When any subscriber removes his receiver from the hook, the short arm of the hook-lever, *L*, makes contact momentarily with the spring, *d*, which grounds the main line wire, *B*, and thus allows a heavy current to pass through the winding, 32, of the drop, *I*. This throws the drop and attracts the attention of the operator. The operator answers the call in the ordinary way by the insertion of one of the plugs, *P*, with which the ringing keys, *l*, in Fig. 260 are associated.

When a substation is to be signaled, the calling plug, *P*, is inserted into the spring-jack, which cuts off the annunciator and connects the keys, *K*, with that particular circuit. Key, l^7, which sends the plus current over both mains in parallel, is then operated to lock the apparatus at all stations without ringing any of the bells; and then the key representing the desired station is pressed which results in ringing the bell, and at the same time in releasing the telephone apparatus at that station by the means already described. At the close of any conversation the key, l^8, sending a negative current over both mains in parallel, is operated to release the apparatus at all stations, restoring the circuit to its normal condition.

CHAPTER XXVIII.

PARTY LINES.—HARMONIC SYSTEMS OF SELECTIVE SIGNALING.

THE third general method of selective signaling on party lines makes use of the fact that every pendulum or elastic reed has a natural period of vibration, and that it can be made to take up this vibration by the action of a succession of impulses of force occurring in the same period as that of the reed or pendulum. A familiar example of this is found in one person pushing another in a swing. The swing has its natural period of vibration, depending on the length of the ropes, and a gentle push applied at proper intervals by the person on the ground will cause the swing to vibrate with a considerable amplitude. If the pushes are applied at intervals not corresponding to the natural period of vibration of the swing, many of them tend to retard rather than help its vibrations, so that a useless bumping results, which produces but little motion.

The utilization of this principle has given inventors a very attractive field of work; but as in the case of the step-by-step systems, the results attained have been of little practical value in telephony, except in so far as they have contributed to the general stock of knowledge on the subject.

The idea of selective signaling between different instruments in the same circuit was used in telegraphy before the birth of telephony. A number of currents of different rates of vibration were impressed upon the circuit by as many different transmitters, each particular rate of vibration being capable of operating a reed in one of the receiving instruments, and producing no effect upon the others. By this means each receiving instrument was capable of picking out only those signals sent by the transmitter having the same rate of vibration, and thus all of the transmitters could be used simultaneously in the same circuit, producing a system of multiplex telegraphy.

The idea as applied to telephony is shown in Fig. 263, where C is an electromagnet connected with the line wire, A A', in series with similar magnets at all of the other stations. B is an armature of soft iron mounted on the post, b, by a short flat spring, thus forming a reed which it is obvious will have a fixed

rate of vibration for any particular adjustment. When a number of current impulses are sent over the line wire having a frequency corresponding to the rate of vibration of the reed, *B*, the latter will be thrown into vibration. If the frequency of the current impulses does not correspond to the rate of vibration of the reed, then the reed will vibrate but slightly, if at all. *D* is a

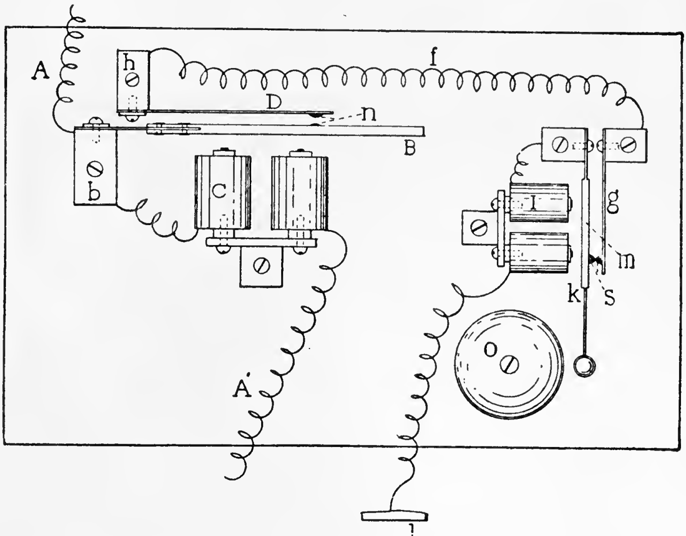


Fig. 263.—Currier and Rice Harmonic Selector.

flexible spring forming a part of a secondary circuit containing an ordinary vibrating bell. When the reed, *B*, is thrown into a sufficiently wide vibration, this latter circuit is closed at the point, *n*, and the bell is sounded.

The reeds at all of the stations are so adjusted as to have different rates of vibration, and by impressing current impulses of a proper frequency upon the line at the central station, the bell at the desired station can be sounded. This illustration is that of a device invented by Messrs. Currier and Rice in 1880.

Fig. 264 shows a signal-receiving instrument designed three years later by Elisha Gray and Frank L. Pope. *M* is an electro-magnet having polar extensions, *m* and *m'* (best shown in the plan view), between which is pivoted the polarized armature, *P*. This will be attracted toward one or the other of the polar extensions, according to the direction of the current through the coils. *O* is a vibrating reed having one end rigidly mounted on the post, *O'*. The rate of vibration of this reed may be varied

by the sliding weight, o, which may be clamped in any desired position by the thumbscrew, o'. N is an armature by which the electromagnet, M, may exert its influence on the reed, O. R is a separate lever pivoted as shown and normally making contact with the reed.

Three such receiving instruments are shown connected in a line circuit, L, in Fig. 265. At the top portion of this figure is shown the transmitting apparatus at the central office. The three transmitters, B^1, B^2, B^3, have each a vibrating reed, b, playing between two pairs of electromagnets, E and e, and main-

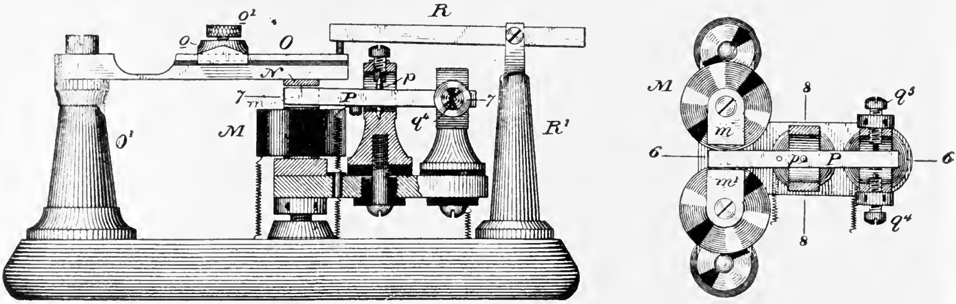


Fig. 264.—Gray and Pope Harmonic Mechanism.

tained in constant vibration by the alternate passage through these magnets of currents from the local batteries, F. The reed of each transmitter is attuned to the rate of vibration of the reed of the corresponding receiver, and therefore current impulses sent to line from any transmitter will operate only one of the receivers.

A constant current is maintained upon the main line, L, by means of a main battery, G, at the central office. When the apparatus is at rest, the circuit may be traced as follows: from the earth at the central office by the wires, w and w^1, to the contact point, v^1, thence by the contact-springs, s', to the contact-stop, v^1, contact-spring, s^2, stop, v^3, contact-spring, s^3, wires, w^2 w^3, and contact-stop, w^8, to the contact-spring, x, and thence by the wire, w^4, to the positive pole of battery, G; thence from the negative pole by the wire, w^5, to the contact-spring, x^1, thence by contact-stop, w^9, and wires, w^6 w^7, to the electromagnet of the signal bell, D, and thence to the line, L, which extends to and through the several stations, and finally to earth at the terminal station.

Upon an insulating support, T, is mounted a series of metallic springs, t^1, t^2, and t^3, carrying buttons, c^1, c^2, and c^3, the free ends of which springs project over the free ends of the series of con-

tact-springs, s^1, s^2, s^3. The contact-springs, $x\ x^1$, are also mounted upon the insulating support, T, their free ends being united by a non-conducting bar, X, which passes directly underneath the free ends of the springs, s^1, s^2, and s^3. The key springs, t^1, t^2, t^3, are connected by wires, y^1, y^2, y^3, with the respective reeds of the

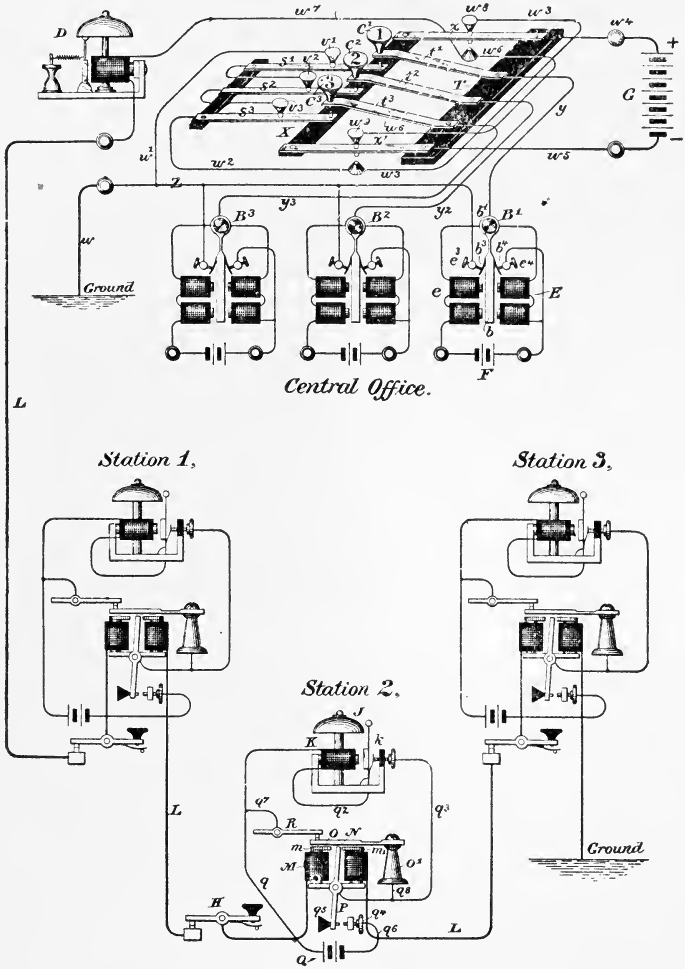


Fig. 265.—Gray and Pope Party Line.

transmitters, B^1, B^2, B^3, after which they are united to a common wire, z, which is connected directly with the earth.

At each substation is placed the receiver already described, a key, H, a battery, Q, and a vibrating bell, J. The polarized armature, P, of the receiver is held in such a position by the

normal current from the battery, *G*, at central as to hold the local circuit open at the point, q^4. Besides this, a shunt is normally closed around the bell magnet, *K*, at each station, by the closure of the contact between the reed, *N*, and the arm, *R*.

To call central the party at a substation has only to depress his key, *H*. This breaks the line circuit and allows the hammer of the central-office bell, *D*, to strike one blow. When the operator at the central office wishes to transmit a call to one of the substations—for example, station 2—she depresses the key, C^2. This establishes a connection between the springs, t^2 and s^2, and at the same time breaks the contact previously existing between the spring, s^2, and the stop, v^2. By the same operation the bar, *X*, is depressed and the springs, x x^1, are respectively removed from contact with the terminals, w^8 and w^9, and brought into contact with the wires, w^7 and w^2. This operation produces the twofold effect of switching the main-line circuit through the appropriate vibrating transmitter reed, B^2, and of reversing the polarity of the main battery, *G*, with respect to the line. The change of the polarity of the main-line current causes the polarized armature, *P*, at every substation to be deflected from its normal position, thus bringing it in contact with the stop, q^4, and closing the circuit of the local battery, *Q*. The closing of the local battery in this manner will, however, in itself produce no effect upon the electromagnet, *K*, of the bell, as the latter is shunted by the contact between the reed, *O*, and the bar, *R*, which rests upon it. The reed, *O*, at station 2 being adjusted to vibrate in response to the reed of the transmitter, B^2, will be set in vibration, and this vibration will cause the loosely pivoted bar, *R*, to hop up and down, interrupt the shunt-circuit, and allow the magnet, *K*, to become active, thus causing the bell, *J*, to ring. The bells at all the other substations, being cut out by the action of their respective shunts, will remain quiescent. The bell of any other station is actuated in precisely the same manner, the only difference being that the reed-armature, *O*, in each instance is adjusted to vibrate in harmony with its corresponding transmitter at the central office and to respond only to currents sent to line by it.

The device of Currier and Rice depended on the vibrating reed to close the circuit through the call-bell, while in that of Gray and Pope the reed served only to break a shunt around the bell. In Fig. 266 is shown a system designed by J. A. Lighthipe of San Francisco, in which the gongs are struck directly by the reed, without the use of an auxiliary magnet. This will be

understood from the diagram without much explanation. The reeds, d^2, e^2, k^2, and l^2, carry hammers adapted to play between the gongs at the substations when acted upon by their magnets, d, e, k, or l. At stations, A and B, these magnets are bridged directly across the two sides of the metallic line, while at stations, C and D, on another line, they are bridged between one side of the circuit and ground. A condenser, d' or e', is in each bridge wire in the former case, to prevent the leakage of current from

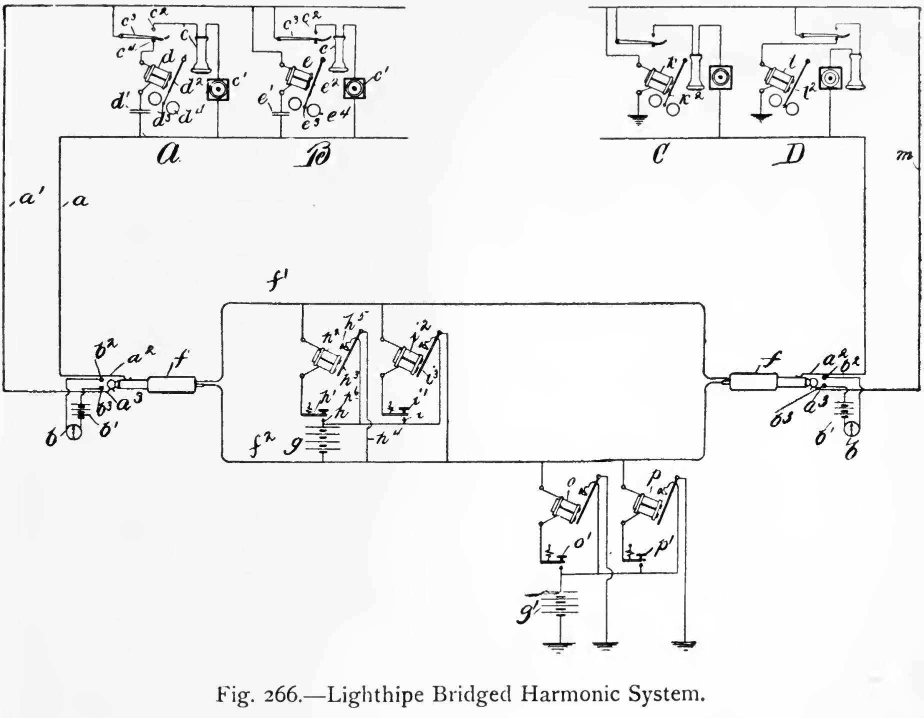


Fig. 266.—Lighthipe Bridged Harmonic System.

the signaling battery, b', when the telephones are not in use. Associated with the cord circuit of a pair of plugs at the central office are the signal transmitters, each having a reed tuned to the rates of vibration of the several reeds of the call receivers. Pressure of the button, h, for instance, closes the circuit of battery, g, through electromagnet, h^2, over the limb, a, of the telephone line through the electromagnets, d and e, at the substations and back by the limb, a', to the opposite pole of the battery.

The magnet, h^2, is thus excited, and attracts the reed, which in its forward movement completes a short circuit around the battery. The reed vibrates back and forth, sending current

impulses over the circuit, and as its rate of vibration is the same as that of reed, d^2, at station A, these impulses will have the proper frequency to actuate that reed and sound its bells. Calling central from the subscribers' stations is performed in precisely the same way as in the Sabin and Hampton and other systems already described.

As the apparatus in this system is arranged on the bridging plan, it is of course necessary that the bell magnets should

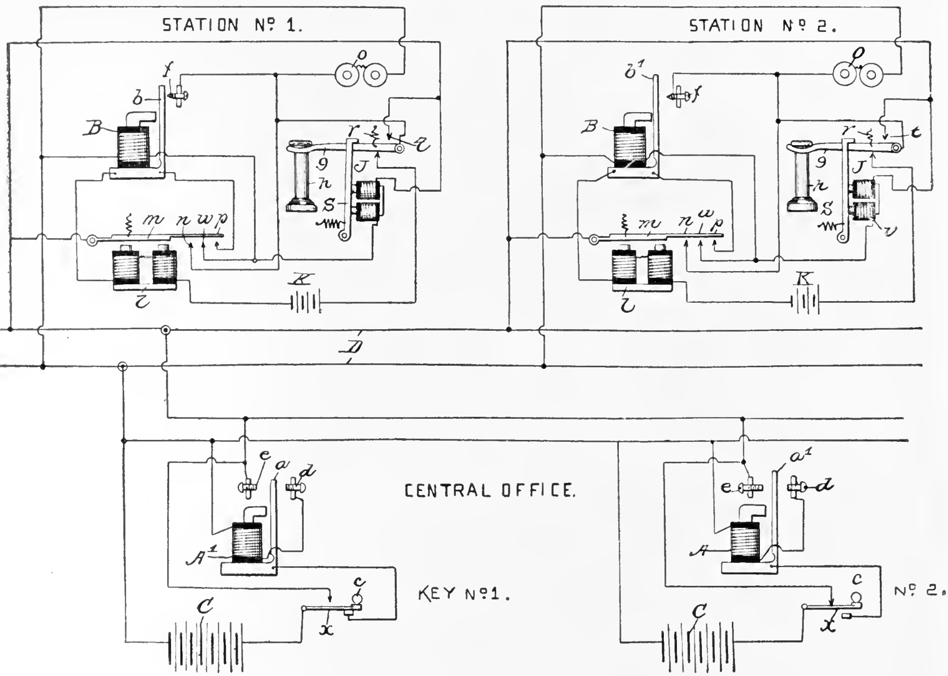


Fig. 267.—Harter Harmonic System.

possess high impedance in conformity with the requirements of bridged lines.

Fig. 267 shows a somewhat elaborate system, invented by Mr. William H. Harter, of Great Falls, Mont., and embodying a lockout mechanism in addition to the signaling devices. In this figure two substations, 1 and 2, are shown connected by a metallic circuit line, with two transmitting devices at the central office. Instead of this connection being permanently made as shown, it would be brought about in practice by a spring-jack and plugs, the transmitting devices being connected across the cord circuit.

The reeds, b and b^1, at the substations, 1 and 2, are tuned to the

same pitch as reeds, *a* and a^1, of their respective transmitters at central.

Upon connecting the cord circuit with the circuit of the line, the battery, *C*, is thrown across the two sides of the line, and current therefrom passes through each of the locking magnets, *v*, in multiple, attracting their armatures, *s*, and locking all of the receiver hooks in their depressed position. Pressure of key No. 1 (for the purpose of calling station No. 1) establishes a local circuit through transmitter magnet, A^1, and the back contact of its reed, thus throwing it into rapid vibration. By means of its front contact, *e*, and the reed, *a*, impulses of current from *C* are allowed to flow over the line circuit, through the magnets, *B*, of the substations; and as these are of the right frequency to actuate the reed at station No. 1, this reed is thrown into vibration, the others remaining at rest.

The reed, *b*, in its vibration completes a local circuit containing a magnet, *l*, and local battery, *K*, and causes it to attract its armature, *m*, against three contacts, *n*, *w*, and *p*. The circuit closed at the contact, *n*, allows the impulses of current coming over the line from the battery, *C*, to operate the bell, *o*. The circuit closed at the contact, *p*, includes also the contact, *n*, and contains the magnet, *l*, and local battery, *k*, and thus serves to keep the armature, *m*, depressed, regardless of the action of the reed. The circuit closed at the contact, *w*, short-circuits the locking magnet, *v*, thus releasing the hook-lever at the station being called.

It will be seen that the act of plugging-in locks all stations, and the closure of key No. 1 throws reed, *b*, at station No. 1 into vibration. This operates magnet, *l*, which closes the bell circuit and also unlocks the hook-lever at that station.

In practice a modification of the central-office circuits would be necessary, for, as shown, the contact made between the vibrating reed at key No. 1 and its contact, *e*, simply closes a circuit from the battery, *C*, which is already made at key No. 2. Each key should, therefore, be disassociated from the other keys during the transmission of the vibratory currents.

These are only a few of a large number of systems depending on the general principles outlined. The harmonic idea is attractive, and may be applied in a great number of ways to the solution of the problem. It has, however, as before stated, been productive of but few practical results. In fact, but one harmonic selective signaling system is, so far as the writer is aware, in practical operation in the United States. It is in use by the

local Bell Company at Sacramento, Cal., and is not an unqualified success, although it has been used over three years. This slight use of the harmonic principle should not detract, however, from the interest in the subject, for a knowledge of the experience of others is a valuable aid in any branch of work, and in none more so than in telephony.

CHAPTER XXIX.

WIRE FOR TELEPHONE USE.

THE wires in use in telephone work are, at present, of copper and iron exclusively. Aluminum will probably, as the price of its manufacture is cheapened, come into extensive use, and it will not be surprising if it eventually supersedes both copper and iron for all except very long distance service. Iron possesses a slight advantage over copper on account of its tensile strength, and a very decided advantage in point of first cost, but in all other respects copper is vastly superior.

The tensile strength of a wire is its ability to resist a pulling stress and the amount of tensile strength is usually expressed in the number of pounds necessary to break a given wire. The breaking stress varies, of course, in the same metal with the size of the wire, that is, with the area of its cross-section. The weight of a given wire varies also in the same ratio, and therefore, in order to have a convenient method for designating the breaking strength applicable alike to all sizes of wire of a certain grade, the breaking stress is frequently expressed in the number of times the weight per mile of the given wire necessary to break it.

Thus, knowing that a certain grade of wire has a breaking strength equal to two and one-half times its weight per mile, all that we have to find out in order to know the breaking strength of any size of this same grade, is the weight per mile of that size. For example, a No. 12 iron wire weighs 165 pounds per mile. This we find out by consulting any table giving the weight of wire, or by weighing a known length of wire. Knowing that the breaking strength of this grade of wire is $2\frac{1}{2}$ times its weight per mile, we may at once arrive at the conclusion that the breaking strength of this particular size is $2\frac{1}{2}$ times $165 = 412\frac{1}{2}$ pounds.

The most important electrical property of line wire is its conductivity per unit area of cross-section. A conductor of iron may be made to have a resistance as low as that of a copper conductor, by giving it about seven times the cross-sectional area. In doing this, however, we make its inductive capacity much greater, and, as has been shown, this is a decided disadvantage. Besides this, the greater weight of an iron wire of the same

conductivity as that of a copper wire, is a very objectionable feature in that it gives the insulators and poles, or other supports, a far greater burden than is necessary.

The resistance of a conductor varies, of course, inversely as the conductivity, and therefore inversely as the cross-sectional area of a uniform wire. Since the weight also varies with the cross-section, it follows that the resistance of a wire varies inversely as its weight per mile. A very convenient method of comparing the relative resistance of various grades of metals used in making wire is to take as the standard of conductivity the *weight per mile-ohm*. The weight per mile-ohm of a conductor is the weight of a conductor a mile long, and of such uniform cross-section as to have a resistance of one ohm. Evidently the better the conductor, the smaller such a wire would be, and therefore a low value of the weight per mile-ohm will indicate a high conductivity. The relative conductivities of any two metals may be determined, knowing the weight per mile-ohm of each. Thus, if the weight per mile-ohm of pure copper is 873.5 and that of a sample wire is 896, then calling the conductivity of pure copper 100 per cent. the conductivity of the sample will be $\frac{873.5}{896} \times 100 = 97$ per cent.

In making conductivity tests, the resistance of the sample tested is measured, and from it is calculated the weight per mile-ohm for that sample. This value can then be compared with the weight per mile-ohm of pure copper as in the above example. By doing this the trouble of calculating the resistance of a pure copper wire of the same dimensions as that of the sample is saved.

The diameter of wire for electrical purposes is usually expressed according to some gauge, and there are, unfortunately, a number of such. Most of the different gauges have been brought into existence by various wire manfacturers and used in connection with their particular products only. In these guages the sizes of wires are referred to by numbers, and in nearly every case the smaller numbers refer to the larger wires. A better way, and one which is coming into more common use, is to refer to the diameter in thousandths of an inch or in mils, as thousandths of an inch are called. A very convenient way of expressing the area of a wire is to give its cross-section in circular mils; a circular mil being the area of a circle, the diameter of which is one mil, or $\frac{1}{1000}$ of an inch. This is better than expressing the area in square inches, because the area in circular

mils is obtained simply by squaring the diameter of the conductor in mils. This very simple relation between the area in circular mils and the diameter in mils is true, because the area of two circles are to each other as the square of their diameters. To reduce the area expressed in circular mils to square inches, multiply it by $\frac{\pi}{4}$ or .7854.

It is a matter of importance, when purchasing wire in any quantity, to measure its diameter accurately, so as to be sure of

Fig. 268.—Circular Wire Gauge.

obtaining the size ordered. It is not an uncommon thing to order a wire in one gauge and have your order filled in another, and the latter gauge usually happens to be smaller than the former.

Circular wire gauges, such as is shown in Fig. 268, are obtainable, and serve their purpose well, but are subject to the disadvantage that a separate gauge is necessary for each particular set of gauge numbers. These gauges are used by inserting the wire into the notches in its periphery until one is found which it just fits; the number corresponding to that notch is then the gauge number of the wire. A far better gauge, although one which is at first a little puzzling to use, is that shown in Fig. 269 and known as the micrometer. It consists of a yoke of tempered steel, in one side of which is mounted a graduated thumbscrew. The wire or other object to be measured is placed between the end of the thumbscrew and the anvil on which it rests when closed, and the screw turned until it makes light contact with the object on both sides. These screws are arranged with forty threads to the inch, so that one complete turn of the screw in a left-handed direction will open the micrometer $\frac{1}{40}$ of an inch. The edge of the collar carried by the screw is divided into twenty-five equal parts, so that a turn of the screw through one of these divisions will open the micrometer $\frac{1}{25}$ of $\frac{1}{40}$, or $\frac{1}{1000}$ of an inch. The shaft on which

the collar turns is divided into tenths of an inch, and each $\frac{1}{10}$ is subdivided into four parts. Thus a rotation of twenty-five divisions on the collar will equal one division on the shaft, or .025 inch. If the collar is turned so as to expose the first division on the shaft and thirteen divisions on itself, then the distance which the jaws have opened will be equal to $.025 + .013 = .038$.

The Brown & Sharpe gauge, usually abbreviated B. & S., is probably used more for copper wire than any other gauge, while the Birmingham Wire Gauge, abbreviated B. W. G., is used to a greater extent for iron wire.

A decided advantage in the B. & S. gauge over any of the others is that the areas of the cross-sections of the various sizes

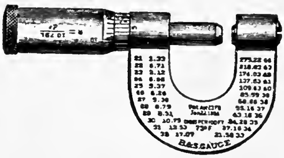


Fig. 269.—Micrometer.

of wire diminish according to a geometrical progression as the gauge number increases. The ratio in this progression is 1.26, or more accurately the cube root of two. From this it follows that when we have increased three sizes we have doubled the sectional area of the wire; and, on the other hand, when we have diminished three sizes we have reduced the cross-section one-half. A very convenient thing to remember in the B. & S. gauge in connection with copper wire is that the diameter of a No. 10 wire is $\frac{1}{10}$ of an inch and that the resistance per thousand feet of this wire is one ohm. These figures are not perfectly accurate, but enough so for most practical purposes. If one desires to make an approximate calculation regarding the size of any wire, he may do so by remembering these figures, which is readily done because of the number of times the number ten occurs in them. For example, suppose it were desired to find the resistance of a No. 13 B. & S. gauge copper wire. Inasmuch as 13 is three sizes smaller than 10, the area of a No. 13 wire will be one-half that of the No. 10, and its resistance per thousand feet double that of the No. 10, or 2 ohms. If the resistance of a No. 14 instead of a No. 13 were desired, it could be found by finding the resistance of a No. 13 as before and multiplying by 1.26, thus obtaining the result 2.52 ohms.

Table II. gives the relative sizes of various numbers of wire in several of the gauges which are or have been in use in this country.

TABLE II.

TABLE SHOWING DIFFERENCE BETWEEN WIRE GAUGES IN DECIMAL PARTS OF AN INCH.

No. of Wire Gauge.	American or Brown & Sharpe.	Birmingham or Stubs'.	Washburn & Moen Manufacturing Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	New British, or Standard.	Old English from Brass Mfrs. List.	No. of Wire.
000000	......	....	.46	....	.464	...	000000
00000	......	....	.43	.45	.432	....	00000
0000	.46	.454	.393	.4	.4	....	0000
000	.40964	.425	.362	.36	.372	....	000
00	.3648	.38	.331	.33	.348	....	00
0	.32495	.34	.307	.305	.324	...	0
1	.2893	.3	.283	.285	.3	....	1
2	.25763	.284	.263	.265	.276	....	2
3	.22942	.259	.244	.245	.252	....	3
4	.20431	.238	.225	.225	.232	....	4
5	.18194	.22	.207	.205	.212	....	5
6	.16202	.203	.192	.19	.192	....	6
7	.14428	.18	.177	.175	.176	...	7
8	.12849	.165	.162	.16	.16	....	8
9	.11443	.148	.148	.145	.144	....	9
10	.10189	.134	.135	.13	.128	....	10
11	.090742	.12	.12	.1175	.116	....	11
12	.080808	.109	.105	.105	.104	....	12
13	.071961	.095	.092	.0925	.092	...	13
14	.064084	.083	.08	.08	.08	.083	14
15	.057068	.072	.072	.07	.072	.072	15
16	.05082	.065	.063	.061	.064	.065	16
17	.045257	.058	.054	.0525	.056	.058	17
18	.040303	.049	.047	.045	.048	.049	18
19	.03589	.042	.041	.039	.04	.04	19
20	.031961	.035	.035	.034	.036	.035	20
21	.028462	.032	.032	.03	.032	.0315	21
22	.025347	.028	.028	.027	.028	.0295	22
23	.022571	.025	.025	.024	.024	.027	23
24	.0201	.022	.023	.0215	.022	.025	24
25	.0179	.02	.02	.019	.02	.023	25
26	.01594	.018	.018	.018	.018	.0205	26
27	.014195	.016	.017	.017	.0164	.01875	27
28	.012641	.014	.016	.016	.0148	.0165	28
29	.011257	.013	.015	.015	.0136	.0155	29
30	.010025	.012	.014	.014	.0124	.01375	30
31	.008928	.01	.0135	.013	.0116	.01225	31
32	.00795	.009	.013	.012	.0108	.01125	32
33	.00708	.008	.011	.011	.01	.01025	33
34	.006304	.007	.01	.01	.0092	.0095	34
35	.005614	.005	.0095	.009	.0084	.009	35
36	.005	.004	.009	.008	.0076	.0075	36
37	.004453	....	.0085	.00725	.0068	.0065	37
38	.003965	....	.008	.0065	.006	.00575	38
39	.003531	....	.0075	.00575	.0052	.005	39
40	.003144	....	.007	.005	.0048	.0045	40

IRON WIRE.

Iron wire corrodes so rapidly that it would be utterly useless for outdoor work were it not possible to protect it to some extent from the action of the weather. This is done by a process called galvanizing, which consists in coating wire with a thin film of metallic zinc. The process of manufacturing iron wire is briefly as follows: the iron, after being brought into the proper condition by various processes of rolling and purifying, is rolled into small rods, after which it is subjected to the process of "drawing." This process consists in pulling the rods through a series of dies, made of steel, each die being smaller than the one preceding it. This is necessarily done while the iron is cold and is termed "cold drawing." The successive drawings of the wire through the dies serves not only to reduce its cross-section, but also to render it excessively hard and brittle, and it is necessary, therefore, to anneal it frequently between the drawings. After the wire has been drawn to the proper size it is annealed and inspected and is then ready for galvanizing. The wire, in order to thoroughly clean its surface, is "pickled" in diluted sulphuric acid for a considerable length of time, after which it is thoroughly washed in order to remove all traces of acid. It is then immersed in hydrochloric acid. The wire is then rolled from one reel to another and between these reels it passes first through a furnace heated to a very high degree, immediately afterward through a vat containing a solution of hydrochloric acid which cools the wire and removes any oxides that have formed during the drawing, and then through a second vat containing molten zinc maintained at a constant temperature by a furnace underneath. The time between the immersion in the last acid bath and the zinc acid bath is short, because these vats are placed very close together, and the metal therefore has no chance to oxidize.

As the proper galvanizing of iron wire is, all things considered, the most important step in its manufacture, it is very essential that reliable tests are made before purchasing wire for outdoor use. Fortunately such a test is a very easy thing to make, but, unfortunately for the ordinary purchaser, they are very seldom made. Several samples of the wire should be selected at random. Each should then be immersed in a strong solution of sulphate of copper for a period of seventy seconds. It should then be withdrawn and wiped clean with a cloth. This process is repeated in all four times. If, at the end of the fourth immer-

sion, the wire appears black, as it did at the end of the first immersion, the zinc has not all been removed and the galvanizing may be said to have been well done; but if the wire has a copper color, either as a whole or in spots, it shows that the zinc has been eaten away and that copper has deposited itself upon the iron wire. In this case the wire should be rejected.

Iron wire which is thoroughly well galvanized is at best rather short-lived, and poor galvanization may result in the total loss of the wire within a year. Well galvanized iron wire has been known to last twelve years, but the conditions were very favorable. Four to six years probably represents a fair average for the life of wire of this kind, but cases are frequent where wires have been so corroded within a year as to make their replacement necessary. In factory districts and in railroad yards where the gases from furnaces come in constant contact with the wire, the life of the zinc coating is very short.

The grades of galvanized iron wire as used by the manufacturers are, if not well understood, very misleading. They are referred to in the following terms: Extra Best Best, Best Best, Best, and Steel, the first three in this list being abbreviated E. B. B., B. B., and B.

Extra Best Best wire is of a very soft, high grade material, having the highest conductivity of all. It has sufficient tensile strength for all ordinary purposes, while its conductivity is far superior to that of the other grades. It has a breaking strength of three times its weight per mile, and the weight per mile-ohm varies from 4500 to 4800, 4700 being a good average.

Best Best is less uniform and tough than the above, but is somewhat better mechanically. It has a breaking strength of about 3.3 times its weight per mile, and its weight per mile-ohm varies from 5300 to 6000.

Best should undoubtedly have been called worst, for as a rule it is a rather poor quality of wire, and before accepting it it should be very carefully tested. It is harder and less pliable than the preceding grades, and has a weight per mile-ohm of about 6500.

Steel wire, which is in reality a rather low grade Bessemer process wire, is much stronger than any of the above grades, but is greatly lacking in conductivity. It has a breaking strength of about five and one-half times its weight per mile, and its weight per mile-ohm varies between 6000 and 7000 pounds.

Steel wire is largely used for telephone work on very short lines, and if well galvanized serves its purpose admirably. In

short city lines no difference can be noticed so far as talking results are concerned between an iron or steel and a copper circuit. The steel wire is, as a rule, cheaper than an Extra Best Best or the Best Best, and has the additional advantage of greater mechanical strength.

The following specifications are in substance those used by the Western Union Telegraph Company in selecting their iron wire:

(1) The wire shall be soft and pliable, and capable of elongating fifteen per cent. without breaking, after being galvanized.

(2) Great tensile strength is not required, but the wire must not break under a less strain than two and one-half times its weight in pounds per mile.

(3) Tests for ductility will be made as follows: Pieces of wire shall be gripped by two vises six inches apart and twisted. The full number of twists must be distinctly visible between the vises on the six-inch piece. The number of twists in a piece six inches long shall not be under fifteen.

(4) The electrical resistance of the wire in ohms per mile at a temperature of 68 degrees Fahrenheit must not exceed the quotient arising from dividing the number 4800 by the weight of the wire in pounds per mile. This is equivalent to saying that the weight per mile-ohm must not exceed 4800. The coefficient .003 will be allowed for each degree Fahrenheit in reducing to a standard temperature.

(5) The wire must be well galvanized and capable of standing the test of dipping into sulphate of copper as stated above.

The British Post Office Specifications require a value of the weight per mile-ohm of 5323.

Table III., taken from Roebling, gives the weight, breaking strength, and resistance of the various sizes and grades of galvanized iron wire:

TABLE III.

Galvanized Iron Wire.

Numbers B. W. G.	Diameters in Mils.	Weights, Pounds.		Breaking Strengths, Pounds.		Resistance Per Mile in Ohms.		
		1000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	304	1607	4821	9079	2.93	3.42	4.05
1	300	237	1251	3753	7068	3.76	4.4	5.2
2	284	212	1121	3363	6335	4.19	4.91	5.8
3	259	177	932	2796	5268	5.04	5.9	6.97
4	238	149	787	2361	4449	5.97	6.99	8.26
5	220	127	673	2019	3801	6.99	8.18	9.66
6	203	109	573	1719	3237	8.21	9.6	11.35
7	180	85	450	1350	2545	10.44	12.21	14.43
8	165	72	378	1134	2138	12.42	14.53	17.18
9	148	58	305	915	1720	15.44	18.06	21.35
10	134	47	250	750	1410	18.83	22.04	26.04
11	120	38	200	600	1131	23.48	27.48	32.47
12	109	31	165	495	933	28.46	33.3	39.36
13	95	24	125	375	709	37.47	43.85	51.82
14	83	18	96	288	541	49.08	57.44	67.88
15	72	13.7	72	216	407	65.23	76.33	90.21
16	65	11.1	59	177	332	80.03	93.66	110.7
17	58	8.9	47	141	264	100.5	120.4	139.
18	49	6.3	33	99	189	140.8	164.8	193.8

COPPER WIRE.

Copper wire is practically indestructible by exposure to ordinary climatic influences. After it is first put up it acquires a thin coating of oxide, and after that no change whatever takes place, so far as can be ascertained. The process of manufacturing copper wire is similar to that for iron wire, with the exception that no galvanizing is necessary. The process of drawing copper wire has been so greatly improved recently that the old fault, lack of mechanical strength, has been almost, if not quite, overcome. Copper wire is now drawn so as to possess a breaking strength of 60,000 pounds per square inch, which is quite equal to that of some grades of iron wire. The difference between hard-drawn copper wire and soft wire is due entirely to the fact

that the hard-drawn wire is not annealed as often between the drawings. The value of the weight per mile-ohm is, for good commercial wire, 682 pounds, the wire having a tensile strength equal to about three times its weight per mile. For hard-drawn wire the percentage of elongation is not nearly so high as that for iron wire, being only about one per cent. before breaking.

The value in pounds per mile-ohm of pure annealed copper is 859, this being based on the international ohm.

In the following table, taken from Roebling's "Wire in Electrical Construction," the weights and resistances of the various B. & S. gauge numbers of copper wire are given:

TABLE IV.

Copper Wire Table.

Numbers B. & S. Gauge.	Diameters in Mils.	Areas in Circular Mils.	Weights per		Resistances per 1000 Feet in International Ohms	
			1000 feet.	Mile.	At 60° F.	At 75° F.
0000	460.	211600.	641.	3382.	.04811	.04966
000	410.	168100.	509.	2687.	.06056	.06251
00	365.	133225.	403.	2129.	.07642	.07887
0	325.	105625.	320.	1688.	.09639	.09948
1	289.	83521.	253.	1335.	.1219	.1258
2	258.	66564.	202.	1064.	.1529	.1579
3	229.	52441.	159.	838.	.1941	.2004
4	204.	41616.	126.	665.	.2446	.2525
5	182.	33124.	100.	529.	.3074	.3172
6	162.	26244.	79.	419.	.3879	.4004
7	144.	20736.	63.	331.	.491	.5067
8	128.	16384.	50.	262.	.6214	.6413
9	114.	12996.	39.	208.	.7834	.8085
10	102.	10404.	32.	166.	.9785	1.01
11	91.	8281.	25.	132.	1.229	1.269
12	81.	6561.	20.	105.	1.552	1.601
13	72.	5184.	15.7	83.	1.964	2.027
14	64.	4096.	12.4	65.	2.485	2.565
15	57.	3249.	9.8	52.	3.133	3.234
16	51.	2601.	7.9	42.	3.914	4.04
17	45.	2025.	6.1	32.	5.028	5.189
18	40.	1600.	4.8	25.6	6.363	6.567
19	36.	1296.	3.9	20.7	7.855	8.108
20	32.	1024.	3.1	16.4	9.942	10.26
21	38.5	812.3	2.5	13.	12.53	12.94
22	25.3	640.1	1.9	10.2	15.9	16.41
23	22.6	510.8	1.5	8.2	19.93	20.57
24	20.1	404.	1.2	6.5	25.2	26.01
25	27.9	320.4	.97	5.1	31.77	32.79
26	15.9	252.8	.77	4.	40.27	41.56
27	14.2	201.6	.61	3.2	50.49	52.11
28	12.6	158.8	.48	2.5	64.13	66.18
29	11.3	127.7	.39	2.	79.73	82.29
30	10.	100.	.3	1.6	101.8	105.1
31	18.9	79.2	.24	1.27	128.5	132.7
32	8.	64.	.19	1.02	159.1	164.2
33	7.1	50.4	.15	.81	202.	208.4
34	6.3	39.7	.12	.63	256.5	264.7
35	5.6	31.4	.095	.5	324.6	335.1
36	5.	25.	.076	.4	407.2	420.3

Abbott gives the following specifications governing the requirements to be made of manufacturers in purchasing copper wire:

COPPER WIRE.

1. *Finish.*—Each coil shall be drawn in one length and be exempt from joints or splices. All wire shall be truly cylindrical and fully up to gauge specified for each size, and must not contain any scale, inequalities, flaws, cold shuts, seams, or other imperfections.

2. *Inspection.*—The purchaser will appoint an inspector, who shall be supplied by the manufacturer with all facilities which may be required for examining the finished product or any of the processes of manufacture. The inspector shall have the privilege of overseeing the packing and shipping of the samples. The inspector will reject any and all wire which does not fully come up to all the specification requirements. The purchaser further reserves the right to reject on reception any or all lots of wire which do not fulfill the specifications, even though they shall previously have been passed or accepted by the inspector.

3. *Apparatus.*—The manufacturer must supply, at the mill, the necessary apparatus for making the examination called for. This apparatus shall consist of a tension-testing machine, a torsion-testing machine, an elongation gauge, an accurate platform scale, and an accurate bridge and battery. Each of these pieces of apparatus may be examined by, and shall be satisfactory, to the inspector.

4. *Packing for Shipment.*—When ready for shipment each coil must be securely tied with not less than four separate pieces of strong twine and shall be protected by a sufficient wrapping of burlap so the wire may not be injured during transportation. The wrappings shall be placed upon the wire bundles, after they have been coiled and secured by the twine. The diameter of the eye of each coil shall be prescribed by the inspector, and all coils shipped shall not vary more than two inches in the diameter of the eye.

5. *Weight.*—Each coil shall have its length and weight plainly and indelibly marked upon two brass tags, which shall be secured to the coil, one inside the wrapping and the other outside.

6. *Mechanical Properties.*—All wire shall be fully and truly up to guage standard, as per B. & S. wire guage. The wire shall be cylindrical in every respect. The inspector shall test the size and roundness of the wire by measuring both ends of each coil,

and also by measuring at least four places in the length of each coil. A variation of not more than 1½ mil on either side of the specified wire-guage number will be allowed, and the wire must be truly round within one mil upon opposite diameters at the same point of measurement. The strength of the wire shall be determined by taking a sample from one end of each coil, 30″ in length. Of this piece, 18″ shall be tested for tension and elongation, by breaking the same in the tension-testing machine. The samples should show a strength in accordance with the following table:

TABLE V.

BREAKING WEIGHT OF HARD-DRAWN AND ANNEALED COPPER WIRE.

Size of Wire, B. & S. Guage.	Breaking Weight of Hard-Drawn—Pounds.	Breaking Weight of Annealed—Pounds.
0000	9971	5650
000	7907	4480
00	6271	3553
0	4973	2818
1	3943	2234
2	3127	1772
3	2480	1405
4	1967	1114
5	1559	883
6	1237	700
7	980	555
8	778	440
9	617	349
10	489	277
11	388	219
12	307	174
13	244	138
14	193	109
15	153	87
16	133	69
17	97	55
18	77	43
19	61	34
20	48	27

A variation of 1½ per cent. on either side of the tabular limits will be accepted by the inspector. The elongation of the wire must be at least three per cent. for all sizes larger than No. 1; 1½ per cent. from No. 1 to No. 10, and 1 per cent. for sizes less than No. 10, for hard-drawn copper wire. The remainder of the sample selected will be tested for torsion. The torsion sample will be twisted in the torsion-testing machine, to destruction, one foot in length being placed between the jaws of the machine. Under these circumstances hard-drawn copper wire shall show

not less than 20 twists for sizes over No. 1; from 40 to 90 twists in sizes from No. 1 to No 10; and not less than 100 twists in sizes less than No. 10. Should the sample selected from one end of each coil show failure to come up to the specifications, the inspector may take a second sample from the other end of the coil. If the average of the results from both samples shall be within the specifications, the coil shall be accepted; if not within the specifications, the coil shall be rejected. The weight per mile shall be determined by carefully weighing 2 per cent. of the number of coils called for in the contract, and the weight thus obtained shall correspond, within 2 per cent. on either side of the result given in the following formulæ:

$$\text{Weight per mile} = \frac{CM}{62.567};$$

$$\text{Weight per 1000 ft.} = \frac{CM}{330.353}.$$

7. *Electrical Properties.*—The electrical properties of the wire shall be determined by the inspector selecting 3 per cent. of the coils, and from them taking lengths of 100 ft., 500 ft., or 1000 ft., at his discretion, and measuring the conductivity of the same with a standard bridge. For soft-drawn copper wire the following resistance per mil-foot will be assumed:

TABLE VI.

RESISTANCE OF COPPER WIRE AT VARIOUS TEMPERATURES.

Temperature in Degrees F.	Resistance, Legal Ohms.	Temperature in Degrees F.	Resistance, Legal Ohms.
0	8.96707	60	10.20253
10	9.16413	70	10.42083
20	9.36473	80	10.64268
30	9.56887	90	10.86806
40	9.77655	100	11.09698
50	9.98777		

For hard-drawn wire the resistance per mil-foot shall be 1.0226 times the foregoing figures. All wire shall be within 98 per cent. of the above figures.

CHAPTER XXX.

POLE-LINE CONSTRUCTION.

THE poles most used in the United States are of Norway pine, chestnut, cedar, and cypress. Southern pine is not as durable as Northern pine, although it is used to a large extent in the South. Canadian cedar, is, however, all things considered, the best wood to use.

The average life of the various woods mentioned are, according to Maver, as follows:

Norway Pine, ...	6 years
Chestnut, ...	15 "
Cedar, ...	12 "
Cypress, ...	10 "

In choosing the kind of pole to be used, the locality must always be considered, for obviously it would be poor economy to bring cedar poles from Canada for the reason that they would last perhaps a few more years than cypress poles, which could be cut on the ground.

Poles should be well seasoned before setting in the ground. This is either accomplished by natural process of drying, or sometimes in a special drying kiln. Before seasoning, however, the pole should be peeled and all knots trimmed. It is easier to do this while the sap is in them than afterwards, and, moreover, the drying takes place in a shorter time if the bark is removed. If the pole is not seasoned before setting or before it is painted, where it is to be painted, the sap is sure to cause a dry rot, which will eventually destroy the pole. The worst feature of this trouble is that the defect is not noticeable on the surface and therefore is likely to cause trouble when least expected. A pole may have all appearances of being perfectly sound and yet be a mere shell, so that, when subjected to some heavy storm, it comes down on the line, perhaps bringing many other poles with it.

Practice differs to some extent concerning the size of poles. Money saved, however, in the purchase of light poles, is usually

saved at a great cost in the future. Table VII. gives a list of the sizes which meet the demands of the best practice to-day.

TABLE VII.

Length.	Diam. at Top.	Diam. 6 ft. from Butt.
25 feet	7 inches	9 inches
30 "	7 "	10 "
35 "	7 "	11 "
40 "	7 "	12 "
45 "	7 "	13 "
50 "	7 "	14 "
55 "	7 "	16 "
60 "	7 "	17 "
65 "	7 "	18 "
70 "	7 "	20 "

Telephone companies that have been in the field long enough have learned that the days of "fence-post" construction are over, and that in the long run poor construction is much more expensive than good. To be sure, in many of the independent installations it is a matter of necessity to use a medium construction throughout on account of the first expense, and in such case if the dimensions of the poles given in the table above are too expensive, they will at least serve as a standard at which to aim. In many cases poles with 5-inch tops will meet all the demands of an exchange, for a few years at least, and it is sometimes expedient to use them.

The number of wires to be carried on any pole line is also a question that will largely determine the diameter of the poles. On the corners, or where a heavy lead is dead-ended, to make connection perhaps with an underground cable, the poles used should be in many cases much larger than those given. In fact, in such cases the heaviest poles that can be had will be none too large, and it is not uncommon to see a 40-foot pole with an 18-inch top at critical points on some of the best constructed heavy lines.

The question of the number of poles to the mile is one that must be decided to meet the particular conditions of the line to be erected. The greater the number of poles the lower the insulation, but this is a very small disadvantage, and is more than offset by the greater freedom from breakage of wires and consequent decrease in the expense of maintenance when the poles are set closely together. In Europe the common practice

is to use as few as twenty poles to the mile. In this country, however, the best practice dictates the use of from forty to fifty to the mile, although many lines are successfully operated with thirty, or less. As a rule, the greater the number of wires carried, the closer and heavier the poles should be. The liability of any particular locality to heavy sleet and wind storms is another factor in determining the size and distribution of poles. In the long-distance lines of the American Telegraph and Telephone Company the standard distance between the poles is 130 feet, making approximately forty to the mile. The standard pole is

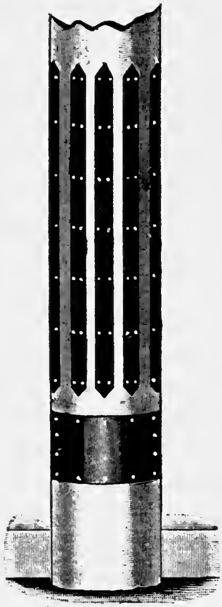


Fig. 270.—Pole Equipped with Guards.

35 feet in length, and, while none are shorter than this, many are much longer. Seventy-foot poles are often used, and in some cases the height of 100 feet is reached.

In cities poles varying from 40 to 60 feet are, as a rule, used. These are generally of Norway pine, as it is somewhat difficult to get cedar poles of this height. It is usually necessary to use a longer pole in city work, in order that the line may be carried above the city electric light and power circuits, and also that the work of firemen may not be interfered with. It is well to protect poles along the streets of cities from the gnawing of horses hitched to them, and also from the wearing effects of

wagon-hubs, which often very greatly weaken the poles at a point where they are least able to stand it. Galvanized steel protecting strips are obtainable for the former purpose, and what are termed butt-plates, about 15 inches by 18 inches by $\frac{3}{16}$ inch thick, of the same material, may also be purchased from supply dealers for the latter purpose. A pole thus equipped is shown in Fig. 270.

In Table VIII. is given some useful information concerning the weights of poles of various sizes and the number forming a carload.

TABLE VIII.

WOOD POLES.—CEDAR.

Length.	Top.	Weight in lbs.	No. to Carload.
25 feet.	5 inches.	200	120
25 "	6 "	275	110
30 "	6 "	325	100
30 "	7 "	450	80
35 "	6 "	500	120
35 "	7 "	600	110
40 "	6 "	700	100
40 "	7 "	800	90
45 "	6 "	950	82
45 "	7 "	1100	60
50 "	6 "	1250	40
50 "	7 "	1450	25
55 "	6 "	1500	30
55 "	7 "	1800	25

NORWAY PINE.

Length.	Top.	Weight in lbs.	No. to Carload.
40 feet.	7 inches.	1100	90
45 "	7 "	1200	80
50 "	7 "	1350	72
55 "	7 "	1500	65
60 "	7 "	1700	55
65 "	7 "	2000	45
70 "	7 "	2400	50
75 "	7 "	2800	45
80 "	7 "	3400	35
85 "	7 "	3800	30

It is not customary, in this country, to treat poles with any preserving process, but it is always well to coat the pole for a distance of six feet from the butt with pitch, before setting it.

It is also well to give city poles two coats of good oil paint, and a very neat appearance is added if the lower portions are painted black to a distance of six feet above the ground, while the remaining portion is painted some light color. In Europe a process termed creosoting is meeting with great favor for preserving telephone and telegraph poles. It is the cheapest of all known expedients of this kind and consists, briefly, in placing the pole in an iron chamber from which the air may be exhausted. This causes the sap and all other juices from the wood to ooze out from its pores. After this steam, at a pressure of about 100 pounds to the square inch, is admitted to the cyclinder and the poles are subjected to this treatment for about four hours. After this crude petroleum is forced into the cyclinder under a pressure of about 300 pounds to the square inch, and it is found that it penetrates to the very heart of the poles, thus adding very materially to their lasting qualities. Cases are cited where poles treated by this method have been perfectly sound after having been in service for a period of twenty years.

Another process, termed vulcanizing, consists in heating the pole in a closed vessel for several hours to a temperature of about 500° F. The principle in this treatment is that the intense heat causes the sap in the wood to coagulate, after which it can produce no evil effects. This would apparently be cheaper even than the creosoting.

The cross-arms carrying the insulators are preferably of sawed yellow pine. Two sizes are in general use, the standard being 4¼ by 3¼. The lengths vary from 3 to 10 feet, according to the number of pins or insulators to be used. Table IX. shows the lengths of the various standard cross-arms; also the spacings of the pin-holes.

TABLE IX.

Length.	Number of Pins.	Spacings.		
		End.	Center.	Sides.
3 feet.	2	4 in.	28 in.	
4 "	4	"	16 "	12 in.
5 "	4	"	18 "	17 "
6 "	4	"	22 "	21 "
6 "	6	"	16 "	12 "
8 "	6	"	18 "	17½ "
8 "	8	"	16 "	12 "
10 "	8	"	17½ "	15¾ "
10 "	10	"	16 "	12 "

The standard size of pin for the above arm has a $1\frac{1}{2}$-inch shank, and arms of this size are usually bored accordingly. They are

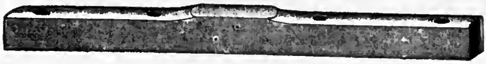


Fig. 271.—Four-Pin Cross Arm.

also bored as shown in Fig. 271 with two $\frac{1}{2}$-inch holes for lag-screws used in attaching them to the poles.

Another size of cross-arm, called the telephone arm, has come into use to a considerable extent for cheaper installation. The size of this arm is $2\frac{3}{4}$ by $3\frac{3}{4}$, being $\frac{1}{2}$ inch smaller in each dimen-

Fig. 272.—Lag-Screw.

sion than the standard. These arms are usually bored for $1\frac{1}{4}$-inch pins and the length of a ten-pin arm is only $8\frac{1}{2}$ feet. The various dimensions are shown in Table X.

TABLE X.

Length.	Number of Pins.	Spacings.		
		End.	Center.	Sides.
24 in.	2	3 in.	18 in.	
30 "	2	"	24 "	
36 "	2	"	30 "	
42 "	4	"	16 "	10 in.
62 "	6	"	16 "	10 "
82 "	8	"	16 "	10 "
102 "	10	"	16 "	10 "
120 "	12	"	16 "	10 "

All cross-arms should be given two coats of good metallic paint, usually red, before setting in position. In order to attach them to the pole a gain is cut in the pole of such dimensions as to accurately fit the longest side of the cross-arm. The gain should not be more than one inch deep, however, for the reason that a greater depth is likely to weaken the pole unduly. The gain should be given two coats of good white lead before the cross-arm is put in place. The common way of attaching the

cross-arms to the pole is by two lag-screws of the type shown in Fig. 272. These are of such length as to reach almost through the pole, and their threads are cut in such a manner that they may be driven part of the way home. A better practice now is to attach the cross-arm to the pole by means of a single carriage bolt extending entirely through the arm and pole, being secured by a nut and a washer. This method has an advantage over the use of lag-screws in that the hole for the carriage bolt may be bored perfectly smooth and clean, and of such size as to accurately fit the carriage bolt, so there is little chance for rotting. A slightly better way, perhaps, but one which is not easy to follow on account of the varying sizes in pole tops, is to bore no hole whatever through the pole, but to attach the cross-arm by means of a U-bolt extending through the cross-arm and around the pole and secured from the front by means of two nuts. This means of attaching is often used in the case of sawn poles where the tops are of uniform size.

The arm is further braced in any case by the use of wrought-iron or steel strips, commonly termed cross-arm braces. These should consist of straight, flat bars not smaller than $1\frac{1}{4}$ inch wide by $\frac{1}{4}$ inch thick, and varying in length from 20 to 30 inches. A hole is usually punched in one end for the reception of a $\frac{1}{2}$-inch or $\frac{5}{8}$-inch lag-screw and in the other for a $\frac{3}{8}$-inch carriage bolt. The two braces for each cross-arm are attached by single lag-screws to the pole at a distance varying from 16 to 18 inches from the bottom of the arm. The other ends of the braces are attached by carriage bolts to the cross-arms at points about equal distances from the pole. In all cases suitable washers should be used under carriage bolt nuts and heads, and under lag-screw heads where they are used in attaching an arm to the pole. All hardware to be used on poles, such as bolts, washers, braces, etc., should be thoroughly galvanized and should be made to stand the same test that is required on galvanized iron wire—that is, four successive plunges of seventy seconds each in a saturated solution of sulphate of copper without removing all of the zinc coating. The pins most commonly used are of locust or of oak. The former is by far the better, as it is the stronger and more capable of resisting the action of the weather. It is, however, nearly twice as expensive as oak. The pins should be turned from split wood in order that they may not be cross-grained, and all pins should be given two coats of the same kind of paint that is used on cross-arms.

In some cases on corners, or in places where excessively heavy

strain will be brought upon a pin, it is advisable to use a wrought-iron or steel pin, but these must be used with caution, as in many cases they have proven inferior to wooden pins, being so soft that they bend into a horizontal position when subjected to the strain.

The insulators used in this country are universally made of glass. Blown glass has been found to be much superior in insulating qualities to molded glass, but the latter is so very much cheaper that it is always furnished. Fig. 273 shows a form of

Figs. 273 and 274.—Pony and Double-Petticoat Glass Insulators.

insulator largely used in telephone work, called the "pony" insulator, and Fig. 274 shows another style, termed the "double-petticoat" insulator. It is so termed from the fact that it has two lower flanges, as shown in section, the idea of this being that the path for leakage from the line to the pin is thereby rendered considerably longer, the leakage current having to pass up and down the surfaces of both petticoats in series.

Glass is not as suitable a material for insulators as porcelain, which is largely used in Europe. It is more brittle and does not possess such high insulating qualities. A more serious defect is, that it gathers moisture on its surface to a much larger extent than porcelain, thus affording a better path for leakage currents. In an interesting series of experiments described by Abbott it was found that the insulating quality of glass insulators varied largely with the condition of the surface of the insulators. These experiments were conducted over a period of one hundred and fifty days, observations being made once a day. The general result indicated that the greatest loss in insulation occurred during foggy or misty weather. During heavy rainstorms the insulation was somewhat higher, and after the storm, when the insulators had been dried, the resistance of the line was con-

siderably higher, owing to the cleaner condition of the surface. In good weather the double-petticoat insulators gave much higher resistance than the single of corresponding size, but during a rainstorm the double-petticoat form was inferior to the single, although it was found to dry more rapidly after a storm.

The determination of the pole-line route is a matter of no small importance. Right of way must be secured, and this usually calls forth all the ingenuity of the party unfortunate enough to be assigned to that duty. Before distributing the poles and other material the route should be thoroughly studied in every detail. Stakes should be driven marking the location of the poles. It should be borne in mind in locating these stakes that bends in the pole line should be avoided wherever possible, that the ground should be of such nature as to form as good a support as possible for the pole, that there will be no interference from trees, houses, or other poles, and lastly that the route shall be as direct as possible. When a turn must be made it should be so located if possible that the guy wire required to hold up the corner will have suitable anchoring ground. Lack of attention to these preliminary details too often brings an endless amount of trouble in the way of rehandling of poles, redigging of holes, and similar useless labor.

When the ground is level, or gently undulating, no provision need be made for grading the pole tops. Where, however, the country is hilly it is well to make a survey of the route with a level, placing the instrument between each successive pair of stakes and taking a front and back sight from each position to the adjacent stakes. A record of the data thus obtained will enable one to plat the vertical section of the route. The profile of the pole tops may then be platted, care being taken to smooth out all sharp bends in it. This is accomplished by putting the tallest poles in the hollows and the shortest on the hilltops. The same results may be accomplished, though not so well, without the use of the level, but it requires an experienced eye to do it to best advantage.

After having decided on the location of the poles, the length of pole for each point, and all other preliminary details, such as placing of heavy poles at the corners, the poles may be hauled and distributed along the route. They should be laid with the butt near the stakes and pointing downhill if on a grade.

The poles are distributed along the route by any available means. If the line runs along a railroad, they may be rolled from the flat car at the proper intervals, and carried to their

places by carry-hooks (Fig. 275). If the line is a long one, and does not follow the line of a railroad, the poles should be un-

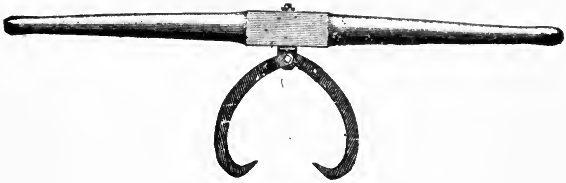


Fig. 275.—Carry Hook.

loaded from the cars at convenient points, and hauled to their proper locations by wagons.

The cutting of gains and the peaking of the pole may be facilitated by the use of a template, shown in Fig. 276, by which the

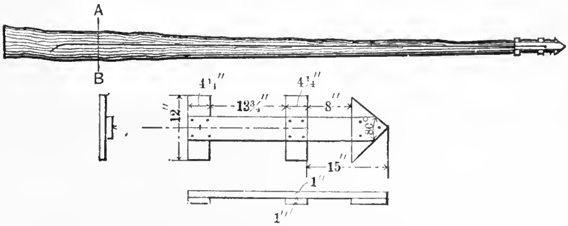
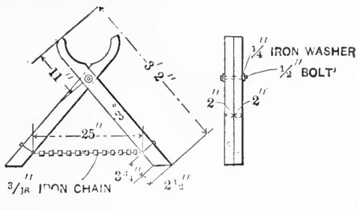


Fig. 276.—Gaining Template.

gains and peak may be marked out. A pole-buck, constructed as shown in Figs. 277 and 278, and used as in Fig. 279,* will also be



Figs. 277 and 278.—Pole Buck.

of great aid in the work. The spacing between the gains, shown on the template in Fig. 276, makes the distance between the cross-arms 18 inches. Many construction men prefer 20 inches.

*For the half-tones and some of the detailed cuts of construction tools in this chapter we are indebted to an excellent article in the *American Electrician*, by Mr. S. H. Dailey, entitled "Erecting a High-Voltage Transmission Line."

Where a greater number of arms are to be used the distance from the top of the top arm to the peak should be reduced to 10 inches.

Poles of medium length may, under ordinary circumstances, be raised with the cross-arms in place, and, as they are much more

Fig. 279.—Gaining Poles.

easily attached on the ground, this should always be done where possible.

In digging the pole holes long-handled digging shovels (Fig. 280) and spoon shovels (Fig. 281) having seven- and eight-foot

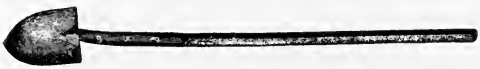


Fig. 280.—Long Handle Digging Shovel.

handles are used in conjunction with eight-foot steel digging bars, shown in Fig. 282. Sometimes the post-hole auger is used,

Fig. 281.—Spoon Shovel.

but this is only where the conditions are very favorable. Dynamite, judiciously applied, is now being used successfully in digging

Fig. 282.—Digging Bar.

holes, even where the soil is of such a nature as not to absolutely require its use.

No definite rule can be given for the depth at which poles should be set in the ground. The character of the soil, the distance between poles, the number of wires carried, and the sharpness of the turns made in the line must all be considered in determining this question. For average work the data given in Table XI. are believed to be in accordance with the best practice.

TABLE XI.

25-foot	pole,	5½	feet	in	ground.
30	"	"	6	"	"	"
35	"	"	6	"	"	"
40	"	"	6	"	"	"
45	"	"	6½	"	"	"
50	"	"	6½	"	"	"
55	"	"	6½	"	"	"
60	"	"	7	"	"	"
65	"	"	7	"	"	"
70	"	"	7½	"	"	"

On curves or corners the holes should be dug from six inches to one foot deeper than is specified in this table.

After digging the holes the poles are carried or rolled by cant-hooks (Fig. 283), so that its butt is over the hole. A piece of

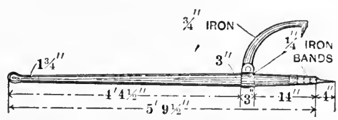


Fig. 283.—Cant Hook.

scantling, or, preferably, a hardwood board in the form of a large paddle, is placed in the hole to serve as a rest for the butt of the pole while it is being raised. The use of this paddle prevents the crumbling of the earth which is sure to result and cause much trouble if this precaution is not taken.

The tools required in raising poles of the average length—from 30 to 50 feet—are five or six pike-poles (Fig. 284), with

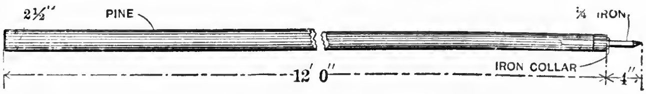


Fig. 284.—Pike Pole.

handles ranging from 12 to 16 feet in length, and two dead men or pole supports, shown in Fig. 285.

The pole is raised slightly and its end slipped into the hole, resting all the while against the paddle or scantling. The small

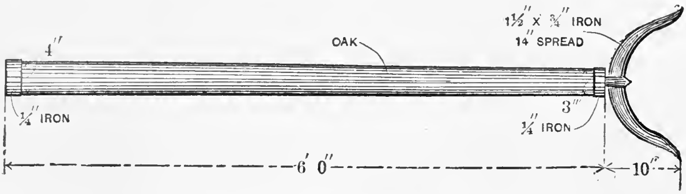


Fig. 285.—Dead Man.

end of the pole is then raised higher and the dead men placed under it, while the men obtain another hold. The pole is raised

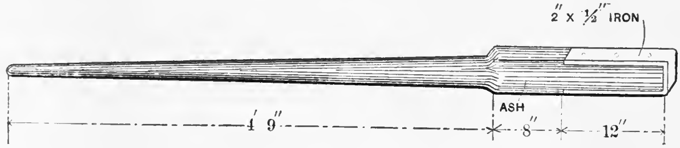


Fig. 286.—Tamping Bar.

gradually, the support being each time moved closer to the butt. When too high to be handled directly, the pike-poles are used

Fig. 287.—Raising Pole.

on its upper part (Figs. 287 and 288), and in this way it is readily raised into a vertical position, slipping into the hole while bearing

against the paddle. It is then braced by the pike-poles, as shown in Fig. 289, and turned by means of cant-hooks, so that the gains or cross-arms, if they were attached before raising the pole, are in proper position; it being remembered that the cross arms should face each other on every alternate pair of poles. The hole is then filled in with the soil which was removed from it in digging, the soil being thoroughly tamped with tamping bars, shown in Fig. 286, from the bottom up. Great care should

Fig. 288.—Raising Pole.

be taken that the shoveling in is not done so fast that the earth cannot be properly tamped. This is frequently the cause of much trouble, and, while it greatly expedites the erecting of the poles, it causes much loss of time and money later, on account of the poles giving way when placed under strain. If the soil is soft a foot-plate should be placed under the butt of the pole. This can be made by fastening together two 2″ x 12″ pieces of oak or hard pine, 2 or $2\frac{1}{2}$ feet long, at right angles to each other. In case the soil is very soft, as in marshy districts, more elaborate means will have to be taken. The hole should be dug in such places much larger than in ordinary instances, and a larger foot-plate may be inserted. A good plan, under these conditions, is to place in the bottom of the hole a layer, 6 inches deep, of

concrete, and, after raising the pole, filling in the entire hole to the surface of the ground with the same mixture, thoroughly tamped into place. For this purpose, and for other cases where

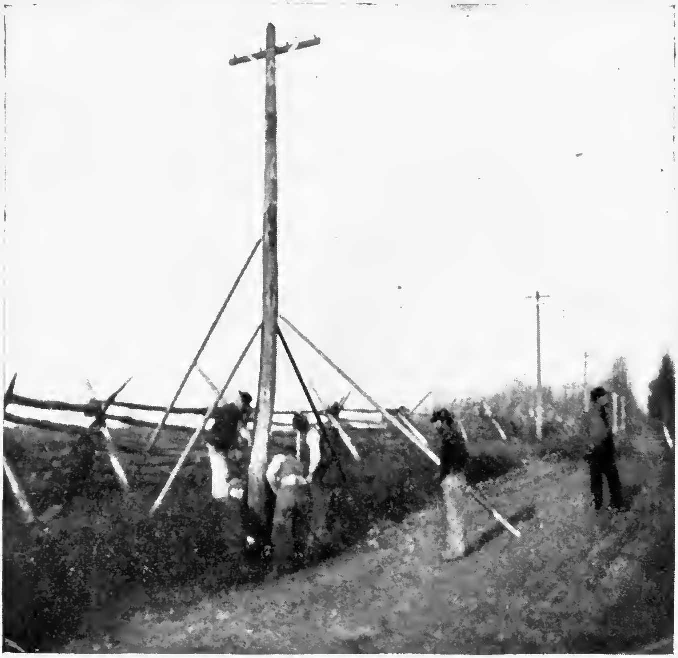


Fig. 289.—Pole Raised.

concrete is needed in line-construction work, the following formulas are given:

FORMULA NO. 1.

Natural Cement, ...	1 part.
Sand, ...	2 "
Broken Stone, ...	3 "

FORMULA NO. 2.

Portland Cement, ...	1 part.
Sand, ...	3 "
Broken Stone, ...	7 "

FORMULA NO. 3.

Portland Cement, ...	1 part.
Sand, ...	$2\frac{1}{2}$ "
Gravel, ...	3 "
Broken Stone, ...	5 "

These three formulas are all good, and the one may be used for which the material may be most readily obtained in the particular location in question. Broken stone is, as a rule, better than gravel, and stones of varying size, up to the size of an egg, are somewhat cheaper than stones of uniform size, because the small stones fill in the interstices between the large ones, and thus require less cement, while the concrete is just as strong.

On a straight line three different kinds of strain must be provided for, namely: the crushing strain, due to the weight of the wires; the side strain, due to wind pressure; and the strain in the direction of the wires. This latter is due to the tension in the wires at the end of the line, or to wind pressure in the direction of the line, or to the tension in portions of the line caused by the falling of a pole or the breaking of a number of wires. In hilly country also considerable strain is caused in the direction of the line itself on a long down grade, due to the actual weight of the wires. The first two strains, that is, the crushing strain and the side strain due to wind, are at times very great, both being augmented by the formation of a crust of ice on the wires and poles during sleet storms. Abbott cites cases where coatings of ice six inches in diameter have been formed on a No. 10 wire throughout its length. These, of course, are extreme cases, but coatings two inches in diameter are quite common. It is customary to provide for the crushing and side strains on a straight line by making the poles heavy enough to stand them without recourse to other methods, although on very heavy lines side guys are often used, even on straightaway work. The sizes of poles given in table on page 361 is sufficient to insure against breakage in such cases under all ordinary conditions.

The strain in the direction of the wires should be provided for by a method of bracing known as head-guying. This consists in running a guy wire from the base of one pole close to the ground to the top of the next, etc., for several poles in succession. About three poles should be guyed from the top of one to the butt of the next, and in the next three the order should be reversed, thus bracing the line in both directions. This, if repeated at intervals of one mile, will greatly strengthen the line against vibration in the longitudinal directions caused by high winds or by the other causes mentioned. On a down grade the head-guys should extend from the butt of the pole on the highest ground to the top of the pole below it. The method of head-guying is illustrated in Fig. 290. When a line is dead-ended at the termination of a lead, or for the purpose of con-

necting with an underground cable, the last three poles should be head-guyed by running a guy wire from the bottom of the

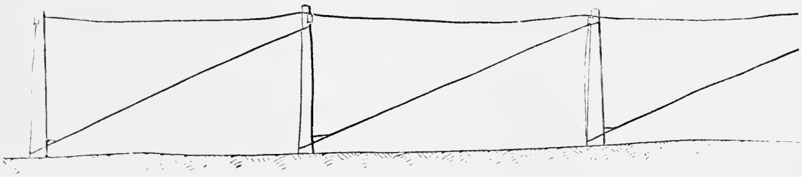


Fig. 290.—Head Guying.

last pole to the top of the next, and so on for three poles. The last pole should be guyed by planting a guy-stub at as great a

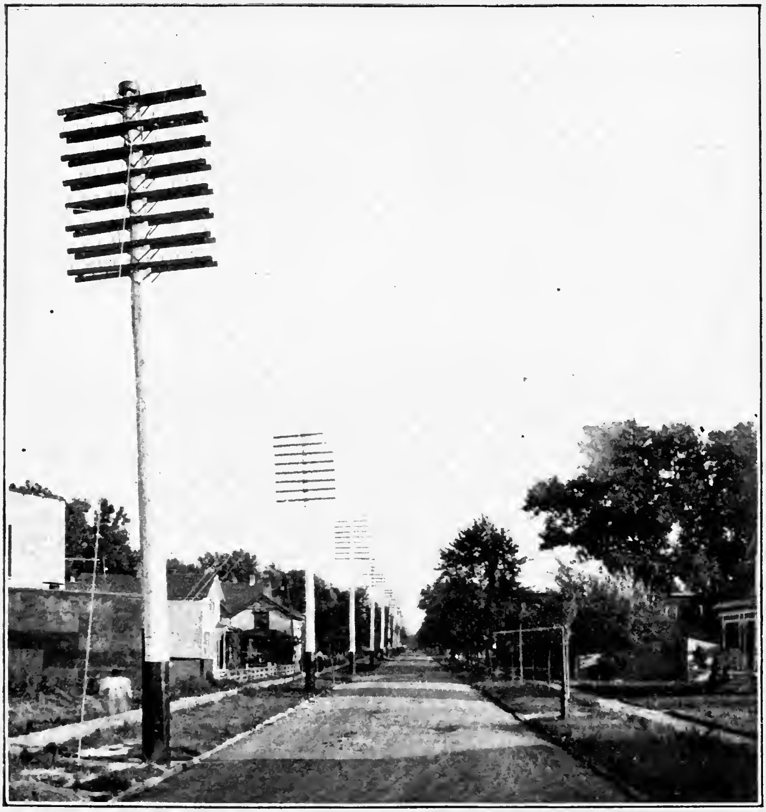


Fig. 291.—Terminal Pole.

distance as possible beyond it, in the direct line of the poles and firmly guying to it. It frequently happens in cities that sufficient room cannot be obtained for dead-ending a pole line in this

manner, and under these conditions some sort of an anchor pole is necessary. Frequently room may be had by planting the anchor at a distance of perhaps ten feet from the base of the pole, as shown in Fig. 291. In this case the guy wire or rod should be made very strong, in order to successfully stand the excessive

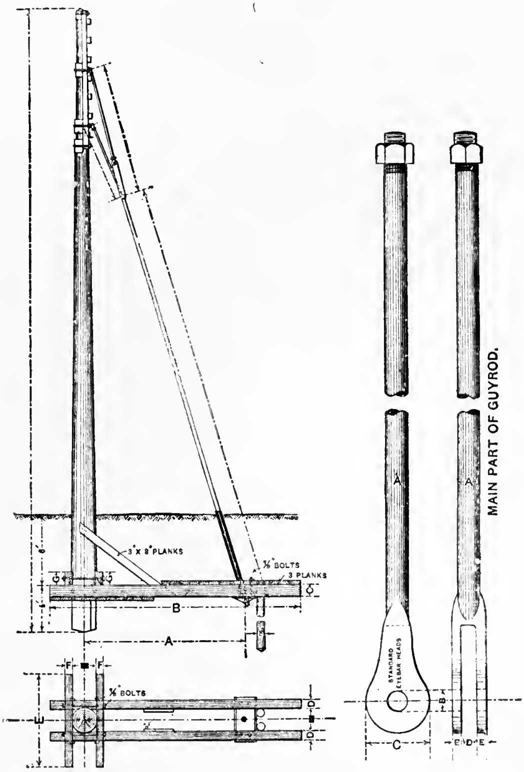


Fig. 292.—Details of Anchor Pole, and Guy Rod.

strain, and the anchor should be buried to a depth of perhaps eight feet, and weighed down by a mass of rock and concrete. As an additional precaution a lattice-work of angle iron is in some cases used to re-enforce the upper portion of the pole for the purpose of equalizing the pull on the guy rod without undue stress on any portion of the pole. In Fig. 292 is shown such a lattice-work, and also a good method of anchoring a pole to be subjected to a severe strain. Structural iron anchor poles are sometimes used for the termination of very heavy leads, and these offer the neatest solution of the problem, but have the disadvantage of being extremely expensive.

When a bend occurs in the line or when a heavy branch lead is taken off at an angle, a very severe side strain is exerted on the poles. These strains must be amply provided for by means of a system of braces which are capable of exerting an opposite pressure to that of the pull of the wires. This is usually done by means of guy wires, connected to the tops of the poles and extending in such direction as to bisect the angle of the bend which the line makes. On long curves a guy wire should be provided for each pole, and it is also well to head-guy each pole. Beginning at the center of the curve, head-guys should extend from

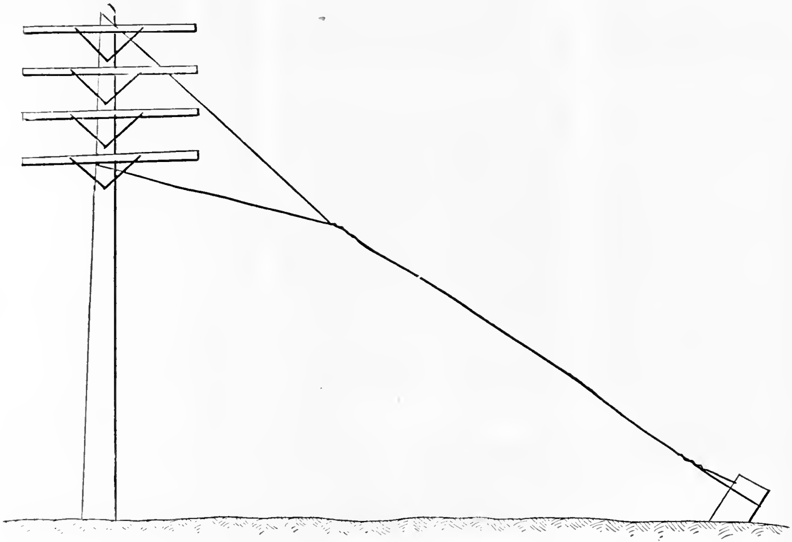


Fig. 293.—Y-Guying.

the base of each pole to the top of the next pole in each direction from the center. The shorter the turn the greater the strain, and the greater, therefore, must be the precaution taken to meet it. The best method of side guying is known as the Y-guy, shown in Fig. 293. Where more than four cross-arms are used a Y-guy should always be employed, as it takes the strain from both the top and bottom arm. To guy from the top of the pole only, as is frequently done, causes the latter to bow toward the center of the curve at the lower cross-arm, and frequently causes the pole to break at that point, usually in the gain of the lower arm. On the other hand, to guy from the lower cross-arm usually causes a pole to bow in the other direction with the same result.

In turning a sharp corner, as, for instance, the corner of a street, it is better to use two poles, which may equally stand the strain. Such a plan is shown in Fig. 294. The wires of the

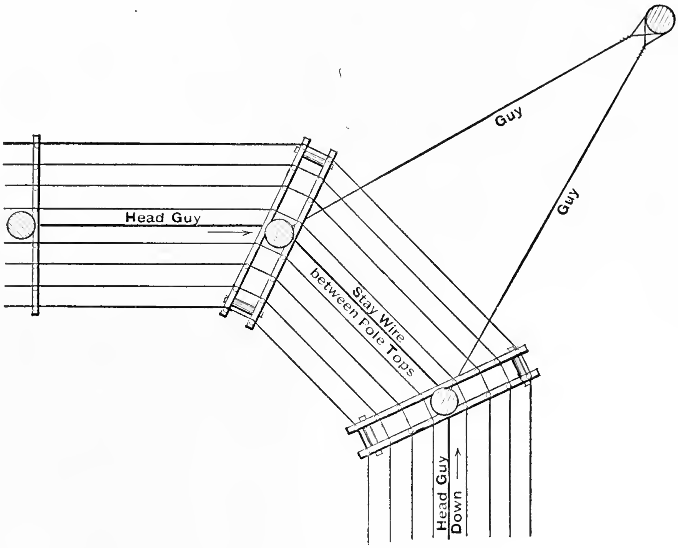


Fig. 294.—Double Pole Corner.

bend are somewhat closer together than those on the straight portions of the line, but this is a matter of almost no importance, and could easily be obviated by making the cross-arms of

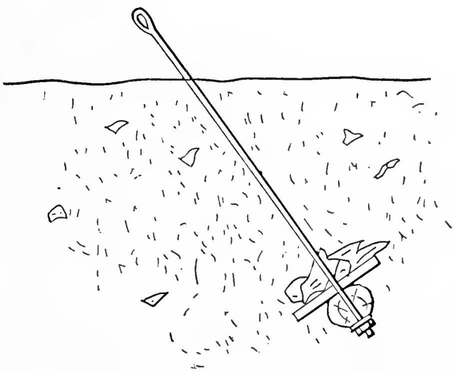


Fig. 295.—Guy Anchor.

these two poles somewhat longer. These two poles should, if possible, be guyed in a manner which will effectually brace them in all directions.

To properly anchor guy wires often requires a good deal of ingenuity, and it is hard to lay down any definite rules, as they frequently have to be planned to meet the existing conditions. One of the most common methods, and a very satisfactory one, is shown in Fig. 295. The anchor log should be not less than ten inches in diameter, and from four to six feet long. A railroad tie is an excellent thing for this purpose. The anchor rod is usually of wrought iron, from six to eight feet long, and from $\frac{5}{8}$ to $1\frac{1}{2}$ inch in diameter, having an eye forged in one end and a heavy screw thread and nut on the other. The rod should pass

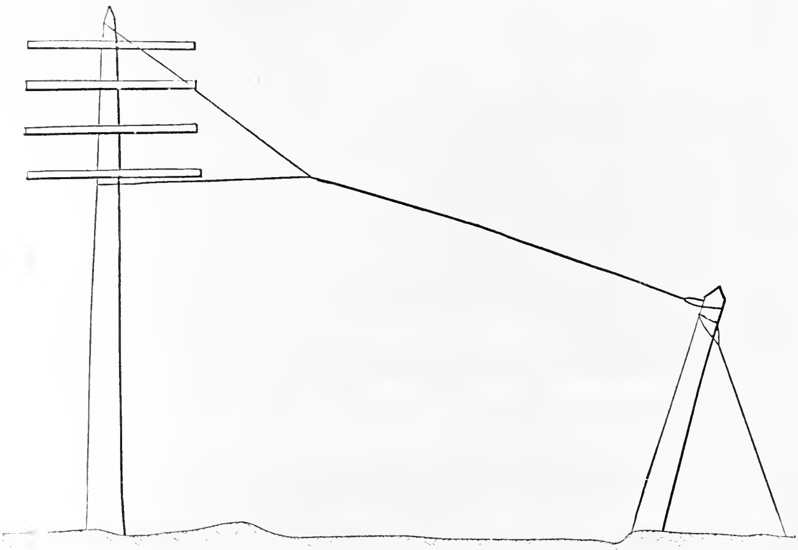


Fig. 296.—Guy Stub and Anchor.

directly through the anchor log and be secured by the nut, a heavy iron washer being placed between the log and the nut. All iron wire so used should be galvanized and subject to the same test as that required for galvanized iron wire. Where a particularly heavy strain is to come on an anchor log it is well to place heavy two-inch planks over the log, and at right angles to the guy rod, and above these heavy stones may be placed. In extreme cases the log should be buried in a mass of concrete.

Another very common way of attaching a guy wire is to a guy-stub, which is usually formed of the stub end of a pole from 8 to 12 feet long, set from 6 to 8 feet in the ground, at an angle of approximately 90 degrees to the direction of the guy wire.

Where this construction is used the guy should be attached to the stub as close to the ground as possible, and never at a greater distance than three feet from the ground, except where additional precautions are taken to anchor the stub itself. Where it is necessary in crossing a road with a guy wire to raise the wire to a greater height from the ground than this construction would allow a longer guy-stub should be used, as illustrated in Fig. 296, and this should be anchored as shown in Fig. 295.

Still another method of providing against side strain is by the use of a pole brace. The pole brace should conform to the same specifications as the regular poles used, and is placed as a prop, usually making an angle of about 30 degrees with the pole itself. It is placed always, of course, on the inside of the curve, and in such direction as to bisect the angle of the wires at that point. The top of the brace should be chamfered and secured to the pole by several twists of heavy guy wire, and may be further held from slipping by the insertion of lag-screws or spikes. The bottom of the pole-brace should be inserted into the ground to a distance of at least three feet, and should rest on a suitable butt plate if the ground is at all soft.

The guy rope should be fastened to the pole by passing it twice around and clamping it by means of some such malleable-iron guy clamp as is shown in Fig. 297. If there is any possi-

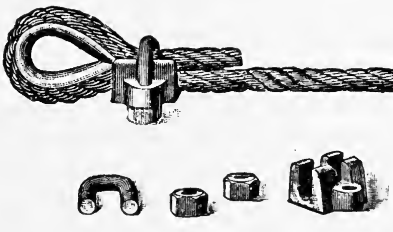


Fig. 297.—Guy Clamp.

bility of the guy wire slipping on the pole this may be prevented by securing it with staples. Care should be taken, however, in the driving of the staples not to injure the guy wire by kinking it.

The wire used in guying may consist of one or more strands of No. 9 or 10 B. & S. steel wire twisted together, but a better plan is to use the regular steel cables, thoroughly galvanized, furnished by the several reliable wire manufacturers. This has the advantage of being more flexible, more easily handled, and, at the same time, stronger for its weight than the single strands

of larger wire. The cable should consist of seven No. 12 steel wires laid up with a $3\frac{1}{2}$-inch twist.

THE STRINGING OF WIRES.

After about a mile of poles have been set and guyed, and the cross-arms, pins, and insulators put in place, the process of stringing, where but a few wires are to be run, consists in placing the reels on hand barrows, as is shown in Fig. 298, or on a

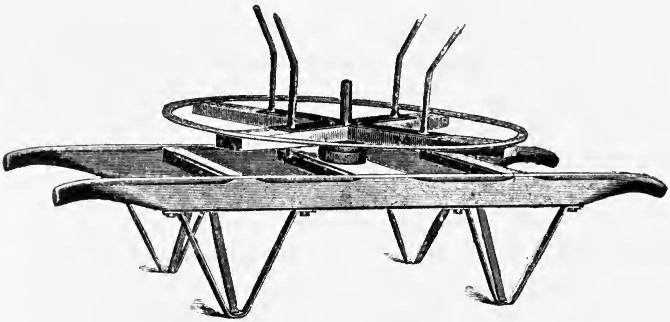


Fig. 298.—Hand Barrow.

cart, and paying them as they go, drawing the wire up to each pole separately. When, however, a larger number of wires are to be run the method is briefly as follows: The separate coils of wire are placed on spindles at the beginning of the stretch to be strung and each is attached to a hole in a "running board," which is of about the same dimensions and has the same spacing as a cross-arm. To the center of this running board a "running rope" is attached—and this is placed on the top of all the cross-arms in the stretch. A team of horses hitched to the other end of the rope then "walk away" with it. A man is stationed on each pole in order to lift the running board over the top of each pole or to properly guide it around. After the wires are all in place each one is separately pulled up to the proper tension, and at a given signal is tied to the insulator at each pole.

Two distinct methods are used for securing proper tension. In each case the force is applied by attaching a wire clamp, commonly known as a "come-along," shown in Fig. 299, and pulling it up with a block-and-tackle or by hand. In one method the proper degree of tension is obtained by the use of the dynamometer, which is merely a form of spring balance. The tension depends on the kind and size of wire, on the distance

between the poles, and on the temperature at time of the stringing. The amount of tension put on each wire is usually taken as about one-third the breaking strength of the wire, which may be found from the wire tables. The other method is to allow a certain sag or distance between the center of the span and the straight line between the points of support. Table XII., which

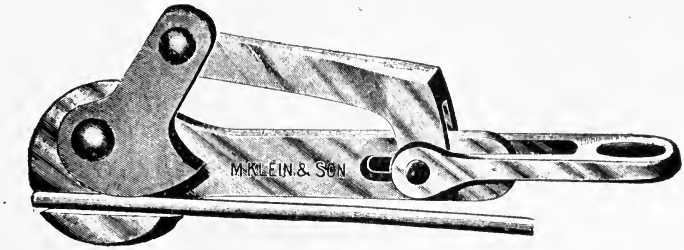


Fig. 299.—Come-along.

is taken from Roebling's handbook on "Wire in Electrical Construction," gives the sag in inches for the various lengths of span at different temperatures, these figures being based on the use of good hard-drawn copper wire.

TABLE XII.

AMOUNT OF SAG IN SPANS.

Temperature in Degrees Fahrenheit.	Spans in Feet.					
	75	100	115	130	150	200
	Sag in Inches.					
−30	1	2	$2\frac{1}{2}$	$3\frac{3}{8}$	$4\frac{1}{2}$	8
−10	$1\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{3}{4}$	5	9
10	$1\frac{1}{2}$	$2\frac{5}{8}$	$3\frac{1}{2}$	$4\frac{3}{8}$	$5\frac{3}{4}$	$10\frac{1}{4}$
30	$1\frac{3}{4}$	3	4	$5\frac{1}{8}$	$6\frac{3}{4}$	12
60	$2\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{2}$	7	9	$15\frac{3}{8}$
80	$3\frac{1}{8}$	$5\frac{3}{8}$	7	$8\frac{5}{8}$	$11\frac{1}{4}$	$18\frac{3}{4}$
100	$4\frac{1}{3}$	7	9	11	14	$22\frac{1}{4}$

It is the practice of a certain company using forty poles to the mile to allow on either copper or iron wire a three-inch dip or sag at the center of spans in the eastern portion of the United

States and an eight-inch sag in the western portion. The reason for the difference in the allowable sag in the East and in the West is due to the fact that far greater variations in temperature occur in the West than in the East.

Two patterns of climbers are in general use, known respectively as the Eastern and the Western climbers. In the East-

Fig. 300.—"Western" Climber. Fig. 301.—"Eastern" Climber.

ern the strap-bar passes up the inside of the leg, and in the Western it is on the outside. These are shown in Figs. 300 and 301.

The tying of wires to the insulators is an important matter, and there are several different methods of doing it. The ordinary method, used almost since the beginning of line construction, is shown in Fig. 302. In this the line wire merely passes

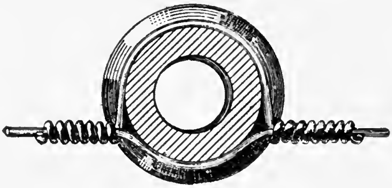


Fig. 302.—Ordinary Tie.

along the side of the insulator and is held in the groove by a tie wire, twisted around the line wire at each end as shown. The tie wires are, as a rule, about sixteen inches long, and made of slightly smaller diameter than the line wire itself, especially in cases of very heavy wire.

Another method, known as the Helvin tie, is shown in Fig. 303. This has been used with considerable success with hard-

drawn copper wire. In this the tie wire is first wrapped around the insulator and twisted once or twice on itself, after which the ends are twisted around the line wire as before.

Still another method of tying the wire to the insulator is shown in Fig. 304. In this, as in the first method, the

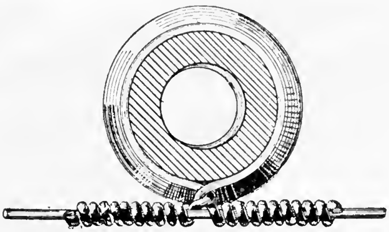


Fig. 303.—Helvin Tie.

line wire is laid in the groove of the insulator and the tie wire is passed entirely around the groove, one end passing down over the line and the other end up under it, the twist being made as shown. This tie is perhaps the best of all where properly made, and is now much used in telephone work. Where a wire is dead-ended it is simply passed once around the insulator and twisted several times upon itself, the twist beginning at a distance of about two inches from the insulator. In the case where transpositions are to be made the free end of the wire should be left long enough to pass over and make connection with the other side of the circuit.

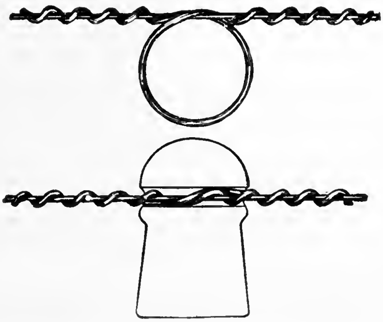


Fig. 304.—Latest Method of Tying.

The joining of wires is a matter which has received much attention. The old style of joint, and one which gives much satisfaction, is shown in Fig. 305. This is known as the Western

Union joint, and is made by placing the two ends side by side and clamping them with a hand vise or with a heavy pair of pliers. With another pair of pliers, held in the right hand,

Fig. 305.—Western Union Wire Joint.

the free end of each wire is twisted tightly around the other wire, as shown.

Another method of joining wires, known as the McIntire sleeve joint, is shown in Fig. 306. The sleeve for making this joint

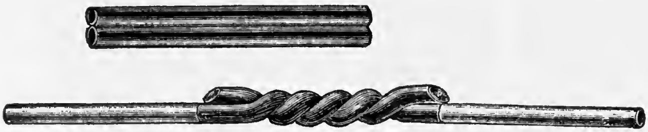


Fig. 306.—McIntire Sleeve Joint.

consists of two copper tubes soldered together and having a bore corresponding to the sizes of the wire to be joined. The ends of the wire are passed in opposite directions through these tubes and are then grasped at each end with a special tool for the purpose and given three distinct twists. This joint is now widely used in practice and is very convenient because the use of solder is not required in order to make it perfect.

Still another connector, known as the Lillie joint, is shown in Fig. 307. The connector in this consists in a sheet of copper curved longitudinally in opposite directions. The wires are

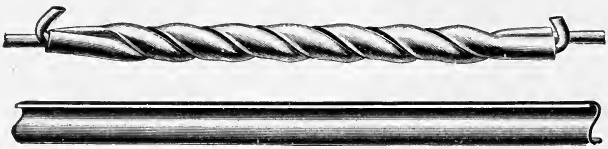


Fig. 307.—Lillie Wire Joint.

slipped in each curve of the strip and twisted in opposite directions, as in a McIntire joint. This joint has not come into such extensive use as the McIntire sleeve, but should prove efficient. Fig. 308 shows how this sleeve may be applied in taking off branch wires, as in the case of attaching bridging telephones to a line.

Practice differs somewhat among construction men as to the matter of soldering wire joints, some claiming that the solder

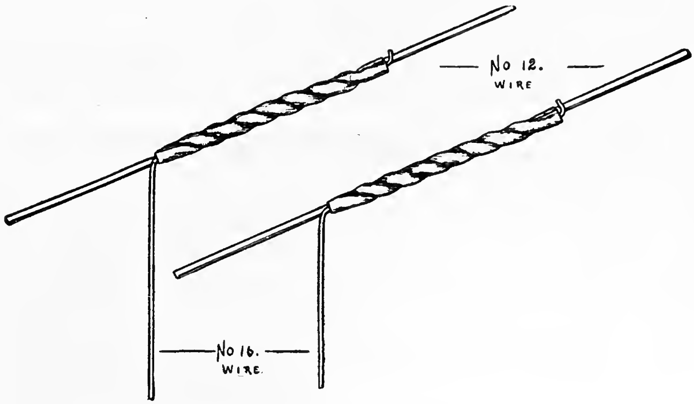


Fig. 308.—Branch Wires with Lillie Joint.

joint gives no better results either as to conductivity or strength than unsoldered ones.

The best practice, however, dictates the use of solder on all except the patent sleeve joints. In soldering a Western Union

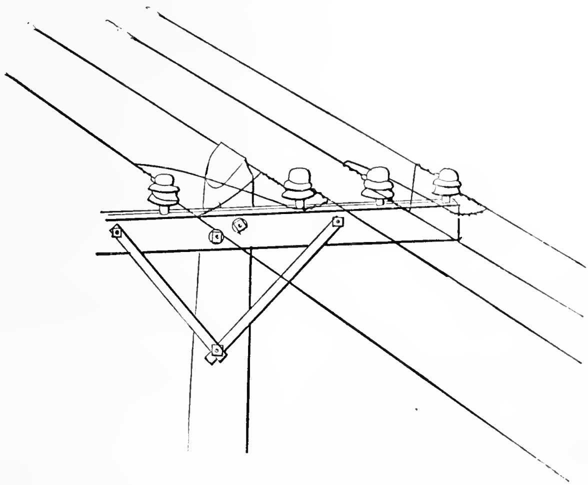


Fig. 309.—Transpositions.

joint, it is well to apply the heat only at the center of the splice. It is sufficient to solder the joint at its center, and the danger of weakening the line by the annealing effect of the heat is reduced.

The method of making transpositions is shown in Fig. 309.

For this purpose transposition insulators having two grooves may be obtained. In making transpositions a good, though more expensive, way is to use double cross-arms at the transposition poles, dead-ending the wires on each, and bridging across by bridle wires in much the same manner as shown.

It is frequently necessary to run a telephone line on the same poles with a high-tension power circuit. Induction from the

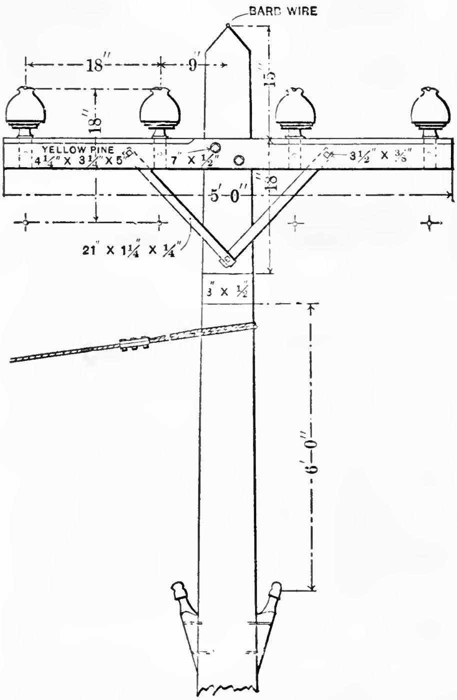


Fig. 310.—Telephone Line and Power Circuit.

power wires is of course under these conditions very likely to render conversation impossible, especially if the current in the power circuit is alternating. Fig. 310 shows the details of a pole thus equipped, the two insulators on brackets being for the telephone line. The latter should be of No. 12 B. & S. copper, and transposed every three poles. In this way a fairly quiet line may be obtained under the most unfavorable circumstances.

CHAPTER XXXI.

OVERHEAD CABLE CONSTRUCTION.

THE tendency of good telephone practice in cities is to bunch the line wires following the same route into cables, and it may be added that there is also a strong tendency toward the placing of these cables underground, this latter being due in large measure to the protests of the public against all overhead electrical construction. Overhead cables are, however, used to a large extent, and there will always be conditions under which their use will be found advantageous.

The overhead cable presents many advantages over the use of bare wires. Besides the fact that in many districts it would be absolutely impossible to handle the required number of wires without the use of cables, on account of lack of space, may be mentioned the following: The lines are rendered far more sightly and offer much less obstruction to firemen in the performance of their duties, for two hundred or more wires, which alone, if bare, would require the use of a pole line carrying at least twenty ten-pin cross-arms, may be crowded into a cylindrical space not over two and a half inches in diameter; the danger of crosses from high-tension or other wires is greatly reduced; the liability to injury in heavy wind and snowstorms is lessened, and the cost of construction is in many cases greatly cheapened.

In regard to the latter point—comparative cost of construction—Table XIII., compiled by the Standard Undergound Cable Company, and based upon average prices for material and labor, is of great interest.

From this it will be seen that while the bare-wire construction may be somewhat cheaper for lines carrying fifty wires or less, the cables have the advantage in this respect when one hundred or more lines are carried.

In the early days of telephony rubber was considered the best insulating material for the wires in cables. A cable so constructed is still largely used by the British post-office system. It is constructed as follows: The conductors are each composed of three strands of tinned copper wire, having a size corresponding to No. 24 B. & S. gauge. These three together form a single

TABLE XIII.

COMPARATIVE COST PER MILE OF OVERHEAD WIRES AND CABLES.

(35 Poles to the Mile.)

Overhead Wires, Bare, Materials, etc.	50-Wire Line. 40-Foot Poles.	100-Wire Line. 45-Foot Poles.	200-Wire Line. 60-Foot Poles.
Poles, Cedar	$ 131.25	$ 166.25	$ 455.00
Poles, Setting	28.00	31.50	44.00
Cross-Arms (10 pins)	61.25	122.50	245.00
Cross-Arms, attaching to poles	17.50	35.00	70.00
Braces and Screws	.60	1.20	2.40
Pins (1½ inch Locust)	17.50	35.00	70.00
Pins, attaching to arms	2.60	5.20	10.40
Insulators	21.00	42.00	84.00
Insulators, attaching to pins	1.50	3.00	6 00
No. 14 B. & S. Gauge Hard Drawn Copper Wire	497.96	995.92	1987.84
Labor Stringing Wire	200.00	380.00	740.00
Total	$ 979.16	$1817.57	$3708.64
LEAD-COVERED AERIAL CABLE.			
Thirty-five Poles (30 feet)	$ 52.50	$ 52.50	$ 52.50
Labor, Setting	24.50	24.50	24.50
One Mile Galvanized Strand	20.59	20.9	51.22
Stringing Same, Including Supports	52.00	52.00	52.00
One-Mile New Standard Cable and Installing Same Complete	1214.40	1636.80	2428.80
Total	$1363.99	$1786.39	$2609.02

conductor weighing twenty pounds per mile and having a resistance of 45 ohms. Each conductor is covered with two coats of non-vulcanized rubber, after which they are taped with rubber-coated cotton and covered with ozokerite. The wires are then twisted together in pairs and the required number laid up into a cable and served with jute and wrapped with tape impregnated with bituminous compound. The whole core is then again coated with the bituminous compound, served with hemp soaked in a compound of gas-tar, and again treated with the bituminous compound. It is then served with an external coating of tape

and a coating of silicated compound. This has been found to be a reliable cable and thoroughly water-proof.

For short lengths rubber-insulated cable is often used in this country, and under certain conditions is preferable to the lead-covered paper-insulated cable which will be described later. The three-stranded conductor, however, is little used, a single No. 18 B. & S. guage tinned wire being used instead. These are double-coated with rubber and separately tested in water for insulation. After this they are covered with braid, bunched, and the core so formed covered with tarred jute, over which is placed a heavy braid saturated with so-called weather-proof compound.

Table XIV., given below, shows the sizes and weights of the various sizes of this cable as manufactured by a prominent firm:

TABLE XIV.

AËRIAL CABLE RUBBER-COVERED WIRES.

Number of Pairs.	Number of Conductors.	Diameter, Inches.	Weight, per 1,000 Feet Pounds.
3	6	$\frac{9}{16}$	175
5	10	$\frac{11}{16}$	256
10	20	$\frac{29}{32}$	452
15	30	1	633
20	40	$1\frac{1}{8}$	813
25	50	$1\frac{1}{4}$	994

Rubber cables are often incased in lead, in which case the rubber is made somewhat thinner and the braid over the individual wires and much of that over the entire bunch is omitted, because the lead affords protection both from mechanical injury and from the weather.

Rubber-covered cables give excellent results as to insulation and durability; but a serious objection to their use for telephone work is that their electrostatic capacity is very high. This is due to the fact that while rubber is a splendid insulator, its specific inductive capacity is much higher than that of some other insulators. Dry air is the most desirable in this respect, its specific inductive capacity being lower than that of any other known

substance. A great improvement in regard to the electrostatic capacity of cables has been brought about by use of paper insulation between the individual conductors. In the earlier forms of cables so constructed the wires were wrapped with paper, which was afterward impregnated with some insulating material, such as paraffin, having a low specific inductive capacity. It has been found by aërating the paraffin thus used with dry carbonic acid gas that the electrostatic capacity between the conductors was reduced as much as 15 per cent. In order to still further reduce the capacity what are known as dry-core cables have been introduced and have come into extensive use. These are usually formed by wrapping the separate conductors with two layers of dry paper loosely laid on. Sometimes only a single wrapping is used. The two wires which are to form a twisted pair are, after being separately wrapped, twisted together, the length of a complete twist being about three inches. Another way of forming a twisted pair is to lay the two wires upon opposite sides of a strip of paper and twisting the two together with the paper between them. The pair is afterwards served with a single wrapping of paper, forming a complete tube around it. After the twisted pairs are formed, by whatever method, the desired number of them are laid loosely together and covered with a lead sheath, usually one-eighth of an inch in thickness.

The saturated-core cable may be formed in the same way, the difference being that the paper is impregnated with some insulating material before the lead sheath is put on.

The saturated cable has the advantage of not being so susceptible to moisture as the dry core, but its electrostatic capacity is usually 15 microfarads per mile, or higher, while in the dry core capacities as low as .05 microfarad are said to have been attained. It is doubtful if this latter figure could be reached as an average, and specifications for dry-core cables usually require an average capacity of .080 per mile. So long as the lead covering remains intact no difficulty is experienced with the dry-core cable, but when a puncture is made moisture enters to a sufficient extent to greatly lower the insulation of the cable. If the damage is not quickly repaired a considerable length of the cable is apt to be injured, as the moisture finds its way quickly through the dry paper. For this reason, in small telephone exchanges not equipped with the proper means for testing out and repairing cables, the saturated core is most desirable. Where the requisite means are at hand for frequent testings the dry core is greatly to be preferred.

The locating of faults in cables may be facilitated by specifying that one or two small rubber-covered wires be laid through the center of the cables, these wires afterward being reserved as test wires for use in the Varley loop test so often used in locating leaks.

The size of wire used in telephone cables varies from No. 18 B. & S. gauge to No. 22, No. 19 being probably the most common. Specifications usually state that the cable sheath shall be composed of an alloy of lead and tin, the amount of the latter being not less than three per cent. of the entire mixture. This requirement has been made because it has been found that such an alloy is not so susceptible to chemical action as lead alone, an important consideration in underground work. Much difficulty has been found in manufacturing them, however, to secure an even mixture of the lead and tin. The Standard Underground Cable Company are firm advocates of the use of a pure-lead sheath, afterwards treated with an external coating of pure tin, arguing that the tin when mixed with the lead makes the sheath brittle and that the tin will be most effective if all of it is placed on the outside. Notwithstanding this, it is customary, as stated above, to specify that the sheath shall be composed of the alloy.

The use of braiding saturated with a moisture-proof compound placed over the lead sheath is often advocated. Opinions differ as to the advisability of this, but it is probable that its disadvantages outweigh its advantages in either overhead or underground work. The locating of punctures in the sheath is made much more difficult by the use of this braid in overhead cables, for when the sheath is bare they may be often located by mere external inspection; moreover, the braiding considerably increases the expense of the cable, and its only advantage is its prevention of abrasion. This need not occur if the cable is properly supported. In underground work the braiding affords a protection for the sheath during the drawing in process and may afford some protection against chemical action. After it rots, however, the pieces may so thoroughly clog up the conduit as to prevent the withdrawal of the cable, thus not only losing that length of cable, but rendering the duct in the conduit unavailable.

Table XV. gives the outside diameter and the weight per 1000 feet of the various sizes of lead-covered paper cable manufactured by a prominent firm. The conductors are No. 19 B. & S., each being served with two layers of paper.

TABLE XV.

Aërial Cable.

Number of Pairs.	Outside Diameter, Inches.	Weights per 1000 Feet in Pounds.
1	$\frac{5}{16}$	214
2	$\frac{3}{8}$	302
3	$\frac{1}{2}$	515
4	$\frac{9}{16}$	629
5	$\frac{5}{8}$	747
6	$\frac{21}{32}$	877
7	$\frac{11}{16}$	912
10	$\frac{13}{16}$	1214
12	$\frac{15}{16}$	1375
15	1	1566
18	$1\frac{1}{16}$	1758
20	$1\frac{1}{8}$	1940
25	$1\frac{5}{16}$	3232
30	$1\frac{7}{16}$	2748
35	$1\frac{1}{2}$	2985
40	$1\frac{9}{16}$	3176
45	$1\frac{5}{8}$	3365
50	$1\frac{3}{4}$	3678
55	$1\frac{13}{16}$	3867
60	$1\frac{7}{8}$	4055
65	$1\frac{15}{16}$	4241
70	2	4430
80	$2\frac{1}{8}$	4804
90	$2\frac{1}{4}$	5180
100	$2\frac{3}{8}$	5505

Aërial cables are supported on steel rope stretched tightly between the poles or other supports. This is necessary on account of the fact that the cable does not possess the requisite strength to support its own weight. For the heavier cables the messenger wire, as the supporting strand is called, is usually composed of seven No. 8 steel wires twisted together into a rope. Table XVI. gives the common sizes of messenger wire, together with their weights and breaking strengths:

A special strand may be procured, the various sizes of which have about double the breaking strength given for the corresponding sizes in this table.

Table XVI. is useful in determining the size of cable that any messenger wire can safely carry for any given length of span. By referring to the table giving the weights per 1000 feet of cable and, knowing the length of span, the size of messenger wire is readily determined.

TABLE XVI.

MESSENGER AND GUY WIRE.

7 Wires. No.	Approximate Diam. in Inches.	Weight per 100 Feet.	Tensile Strength in Pounds.
8	$\frac{1}{2}$	52	8320
9	$\frac{15}{32}$	42	6720
10	$\frac{7}{16}$	36	5720
11	$\frac{3}{8}$	29	4640
12	$\frac{5}{16}$	21	3360
13	$\frac{9}{32}$	16	2560
14	$\frac{17}{64}$	12	1920
15	$\frac{1}{4}$	10	1600
16	$\frac{7}{32}$	8	1280
17	$\frac{3}{16}$	6	960
18	$\frac{11}{64}$	$4\frac{3}{10}$	688
19	$\frac{9}{64}$	$3\frac{3}{10}$	528
20	$\frac{1}{8}$	$2\frac{4}{10}$	384
21	$\frac{3}{32}$	2	320

TABLE XVII.

SUPPORTING CAPACITY OF GALVANIZED STEEL STRANDS.

7 Wires. No.	Approximate Diam. in Inches.	Spans in Feet.								
		100	110	120	125	130	140	150	175	200
		WEIGHTS IN POUNDS OF 1000 FEET OF CABLE.								
8	$\frac{1}{2}$	2818	2516	2263	2152	2050	1867	1709	1391	1154
9	$\frac{15}{32}$	2520	2247	2020	1920	1827	1663	1520	1234	1130
10	$\frac{7}{16}$	2030	1812	1630	1550	1476	1344	1230	1001	900
11	$\frac{3}{8}$	1580	1409	1266	1204	1146	1043	953	774	640
12	$\frac{5}{16}$	1110	899	890	846	805	733	670	544	450
13	$\frac{9}{32}$	860	765	680	652	620	563	513	414	340
15	$\frac{1}{4}$	585	521	468	445	423	385	352	280	235
16	$\frac{7}{32}$	433	385	346	329	313	284	260	210	172
17	$\frac{3}{16}$	337	300	270	257	245	223	204	165	137

The messenger wire may be supported in several ways, one of which is to bolt a piece of angle iron to the pole and suspend one messenger wire from each of its ends. The wire may be suspended below the angle-iron cross-arm, or it may rest in a slot in

it. There are also several good forms of supports on the market, one of which is shown in Fig. 311.

The cable is supported from the messenger wire in several different ways. Rubber-covered cable is frequently suspended

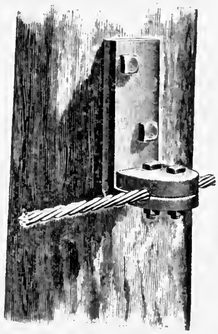
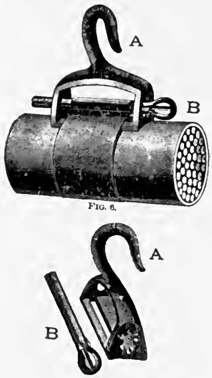


Fig. 311.—Messenger Wire Clamp.

by binding it to the messenger wire by strong tarred marline. The marline is wrapped around both cable and messenger, usually in two directions, to give greater security. The method now most extensively used in supporting lead-covered cables is by means of metallic clips or hangers, adapted to tightly girdle the cable sheath and provided with a hook to slip over the support-



Figs. 312 and 313.—Cable Hangers.

ing wire. There are several good hangers, two styles of which are shown in Figs. 312 and 313. In attaching the one shown in Fig. 312 the metal strip which passes around the cable is first passed for a distance of one inch through the slot in the lower part of the hook. The other end is then bent around the cable

and through the slotted key. The key should then be turned to the left until tight and then locked by driving it endwise until the ears on it engage in the star-shaped hole. The flexible strip in this hanger is made of zinc. The hanger shown in Fig. 313 is of malleable iron and is attached by bending it around the cable with a special tool.

It is a good plan to place a piece of sheet lead $\frac{1}{16}$ inch thick, or a piece of leather or rubber hose, around the cable at the point where the hanger is to be applied; but if this is to be done the additional thickness must usually be allowed for in ordering the hangers.

It is well, in ordering cables, to specify that it shall be placed upon the reels in such manner that both its ends are accessible without unreeling it. Where this is done it is an easy matter to

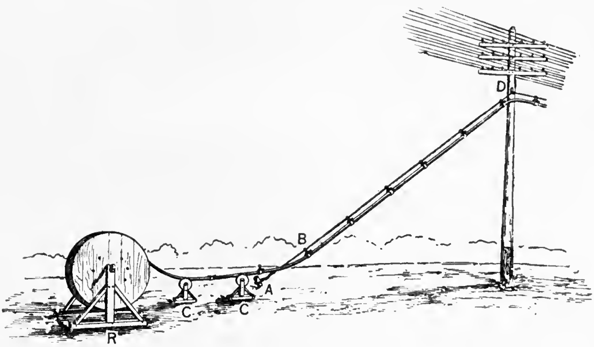


Fig. 314.—Running up Cable.

make tests for continuity of the conductors and for insulation resistance and capacity before the cable is unreeled, and thus any defects which may exist will be known to be the fault of the manufacturer or the transportation company. When the cable arrives both of its ends will be sealed to prevent the entrance of moisture, and, after testing, the ends should be carefully resealed in a manner which will be described later. The ordinary method of hanging cables is shown in Fig. 314, which is taken from Roebling's "Handbook on Telephone Cables," as are several of the succeeding cuts illustrating the method of splicing. The end of the supporting strand, after passing over the last clamp or cable cross-arm, *D*, is firmly secured to a guy-stub driven in the ground at *A*. The reel on which the cable is coiled is placed in line with the messenger wire, and a few feet beyond the stake, as

shown. One or more grooved pulleys, *C C*, mounted as shown, are placed between the reel and stake in such manner as to support the cable as it is paid out. A stout rope, or better a small wire cable, is previously hung on pulleys or hooks below the cross-arms of the entire stretch over which the cable is to be drawn. One end of this is attached to the end of the cable, while the distant end is attached to a capstan or other form of windlass. As the cable passes over the rollers, *C C*, the hangers are attached and are placed one by one upon the inclined messenger wire as they reach the point, *B*. As the cable progresses linemen stationed on each pole lift the hangers over the messenger wire clamp or cross-arm as they pass. In this way the entire length of cable is drawn up to and along the stretch without subjecting any portion of it to an undue strain. The hangers are usually attached at distances of from twenty-four to thirty inches, according to the size of the cable. The work is somewhat expedited if, during the drawing up of the cable, only about every fifth hanger is hooked over the messenger wire. This reduces the labor of the linemen in lifting the hangers over the support. When, however, the forward end of the cable reaches the beginning of the last span, the signal should be given to all linemen stationed on the poles to hook on all of the hangers as they pass, and in this way all of the hangers will be secured in place throughout the entire stretch without going out over the line afterwards.

This method is subjected to one disadvantage in that the sliding of the hanger hooks along the messenger wire tends to loosen them on the cable, sometimes to such an extent that several of them become bunched at one point on the cable. A method for overcoming this disadvantage, and also for expediting the work, has been devised by Mr. F. S. Viele of the Standard Underground Cable Company. In this, carriers, each consisting of a small grooved roller with a hook below it for engaging the cable, are placed upon the messenger wire, and serve to support the cable at frequent intervals instead of the hangers during the process of stringing. At each cross-arm a small switch or side track is placed upon the messenger wire, which serves to displace the carrier rollers far enough to clear the messenger wire, and then to guide them down under the cross-arm and again up on the messenger wire. These side tracks are about three feet long and may be readily attached or detached from the messenger wire. When the forward end of the cable reaches the beginning of the last span of the stretch a man is sent up each pole to place the hangers on the messenger wire and remove the carriers as they pass,

thus leaving the entire cable permanently suspended when the forward end reaches its destination.

It is always well to leave sufficient slack in aërial cables at frequent intervals to allow for subsequent splicing in case repairs are needed. This slack, moreover, frequently saves a cable from serious injury when the pole line is subjected to some severe strain which the cable, if unable to give, would not be able to bear. Attention to this point will often prevent the necessity of splicing in a new piece in the middle of a cable, due to insufficient length for making an ordinary splice.

Where it becomes necessary to splice a cable the greatest care should be taken that no moisture be allowed to enter while the splice is being made, and that the splice shall be so thoroughly sealed at the end of the operation that there will be no possibility of the subsequent entrance of moisture. A suitable staging should be erected on the pole where the splice is to be made, if

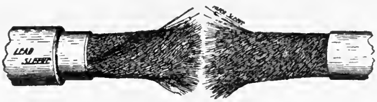


Fig. 315.—Cable Prepared for Splicing.

it is possible to bring the splice within reach of the pole. This can always be provided for in new cable, but sometimes in repairing a leak it is necessary to make these splices from a car suspended from the messenger wire. When all is ready the lead sheath of each end of the cable to be spliced should be cut away for a distance of about twelve inches, the ends of the cable having previously been sawed off square. Boiling paraffin, heated in a large pan on a portable furnace, should then be ladled over the ends of the wire to prevent, as far as possible, any moisture from the atmosphere from entering the cable and also to prevent the untwisting of the paper insulation, which, in a dry-core cable, often gives considerable trouble during the operation of splicing. A lead sleeve, consisting of a lead pipe about two feet long, and of a slightly greater internal diameter than the external diameter of the cable sheath, should then be slipped over one end of the cable and back several feet out of the way. A paper sleeve should then be slipped over each wire of each pair. The pairs in paper-covered cables are usually colored red and white, and as a matter of convenience a paper sleeve should be slipped over all of the red wires on one end of the cable and one of the white wires on the other. This brings the cable ends into the condi-

tion shown in Fig. 315. The corresponding wires of each pair are then skinned for a short distance and twisted together, as shown in Fig. 316, and after a number of pairs are so joined all

Figs. 316 and 317.—Splicing a Pair.

joints should be carefully soldered, particular pains being taken to use no acid flux. Tubular solder provided with a rosin flux inside is convenient for this, or the grease from a tallow candle is perhaps better yet. With a rather large soldering iron these joints may be soldered almost as fast as the iron can be touched to the wire. After soldering, the twists should be bent down as shown in Fig. 317, after which the paper sleeves are slipped over the bare portion of the wires, leaving the completed splice, as shown in Fig. 318. The joints in each pair should not lie opposite

Fig. 318.—Finished Splice on Pair.

each other, and within the space allowed between the ends of the cable sheaths all joints should be staggered as much as possible so as to prevent the formation of a large bunch at any one place. Another point to be remembered is to guard against joining any good wires in one cable to wires known to be bad in the other. Before making these splices all wires should be tested out and the bad ones tagged. Obviously, if a good wire in one length of the cable is attached to a bad one in another, that wire is unavilable for use in either cable. After all of the wires are spliced and

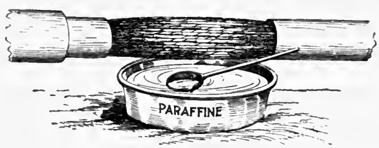


Fig. 319.—Boiling Out.

covered by paper sleeves the cable should be carefully "boiled out," this process being shown in Fig. 319 and consisting in ladling boiling paraffin over the joint until all traces of air bubbles in the hot paraffin disappear. This portion of the work

should never be slighted, as it is one of the most important in the entire operation.

After the "boiling out" process is completed a plain strip of

Fig. 320.—Finished Cable Splice.

white cotton should be wrapped over the splicing, after which the joint should again be boiled out. The joint is now ready for the

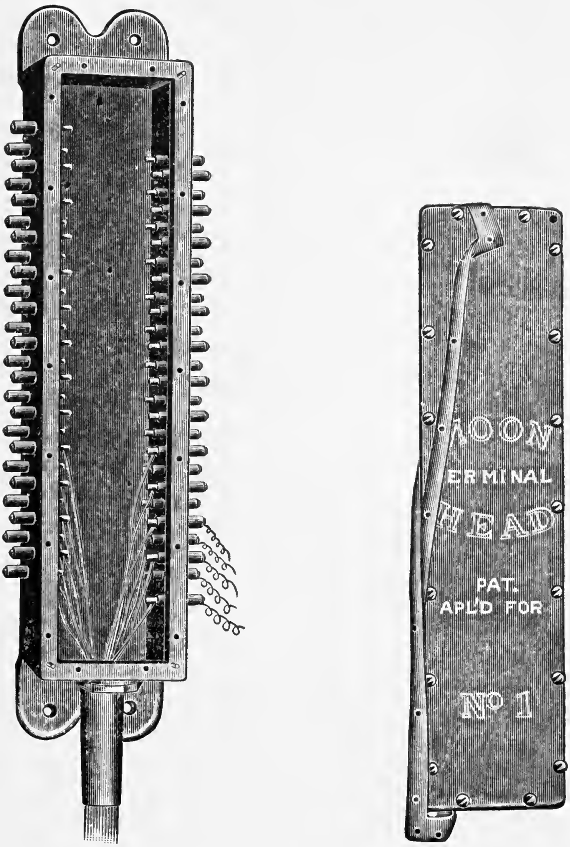


Fig. 321.—Moon Cable Head.

services of a plumber, and upon his work much depends. The section of pipe should be slipped over the splice before it has had time to cool, and the sleeve thoroughly wiped to the cable

sheath at each end by the ordinary method used in joining lead pipes. The finished joint presents the appearance shown in Fig. 320, and when such a joint is properly made that portion of the cable should be practically as good as any other portion.

Whenever it is necessary to leave a cable end exposed all moisture should be expelled by boiling out, after which the end of the sheath should be sealed by a wiped solder joint with as much care as if it were to be a permanent affair. If it is suspected that moisture has entered the end of a cable a short length of it should be cut off and dipped into boiling paraffin, when the presence of moisture will be indicated by the rising of bubbles in the hot

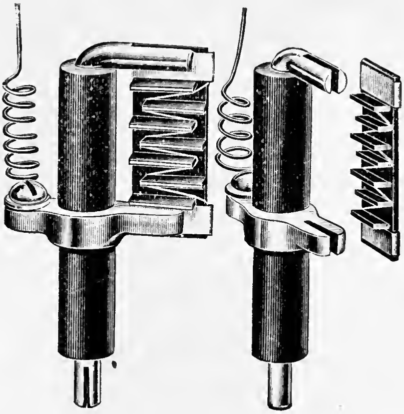
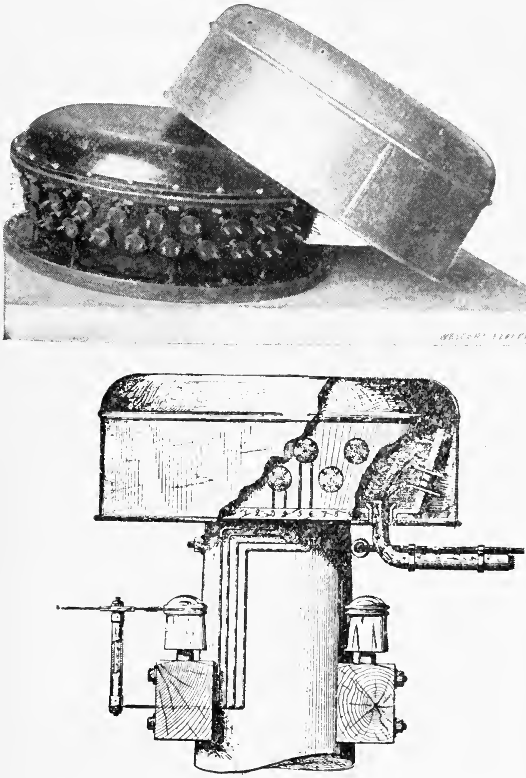


Fig. 322.—Fused Terminal Block for Moon Head.

fluid. If there is room to spare the cable should be cut back, a short length at a time, until it gives evidence of being dry, but if this cannot be done the sheath should be heated with a torch, beginning at a point several feet from the end, and working gradually toward the end, so as to expel the moisture. After this the ends should be thoroughly boiled out and a splice made as already described, or, if this is not to be done, the end should be sealed.

Where a cable terminates means must be provided for distributing its various wires and connecting them to the wires forming parts of the same circuits. For this purpose what are termed cable terminals or cable heads are used, several forms of which are on the market. These usually consist of iron boxes, inside of which are arranged terminals for the wires in the cable. The lower parts of these boxes are usually provided with a brass tube or sleeve adapted to fit over the cable sheath, after which it is secured thereto by a plumber's wiped joint, thus hermetically sealing both

cable head and sheath at that point. The wires of the cable are fanned out to the terminals within the box, which terminals are usually connected through water-tight insulating bushings with their terminals outside of the boxes. After the various connections are made within the box a cast-iron cover is screwed in place, the joints being hermetically sealed by a rubber gasket. On the outside of the boxes are usually provided lightning arresters for



Figs. 323 and 324.—Cook Pole Top Terminal.

each line, the circuit being completed from the inner connectors through these arresters to the outer wires. One of these, known as the Moon cable head, is clearly shown in Fig. 321, in which several wires are shown extending from the tube below the box to one of the terminals within. In Fig. 322 is shown a fused terminal for use with the Moon head. The bushing which serves to lead the terminal pin through the iron casing also carries a brass lug between which and the pin is placed the fuse, mounted on a hard-rubber block as clearly shown. Another form of cable head

which is becoming very popular is known as the Cook pole-top terminal, views of which are shown in Figs. 323 and 324. In this, which is the invention of Mr. Frank B. Cook of the Ster-

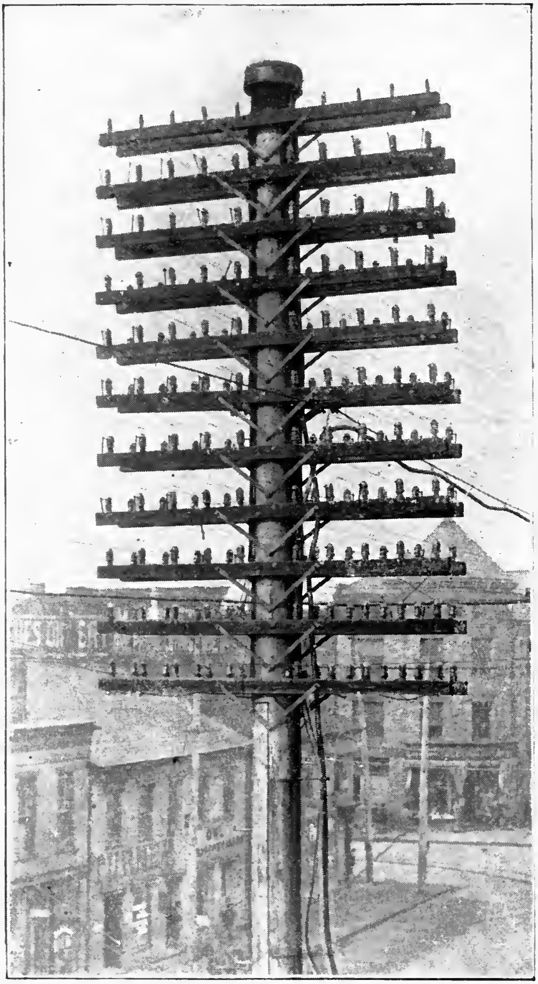


Fig. 325.—Pole Equipped with Cook Terminal.

ling Electric Company, the cable is led up within the cast-iron box, forming the framework for an entire terminal, the various wires being fanned out to conductors arranged in circular rows around the inside of the box. Connection is made through suitable air-tight plugs with outside circuits, the line wires being fused at the insulator, as shown at the left-hand lower portion

of Fig. 324. Before screwing on the cover several lumps of unslacked lime are placed within the box, after which the cover is screwed on, being hermetically sealed by rubber gasket as in the other form described. This lime absorbs any slight moisture which may be in the box at the time, and the fact that it has in many cases remained unslacked for years proves conclusively that these terminals may be made perfectly moisture-proof. After all connections are made a sheet-iron cover is placed over the entire terminal.

This terminal, as its name implies, is placed at the top of the pole in a manner shown in Fig. 325.

A much less expensive method of terminating cables than any so far described consists in the use of what are termed pot-heads, and while these present a somewhat homely appearance they are very effective, and are used to a large extent by many of the Bell and other companies. There is no doubt but that a pot-head terminal, properly constructed, forms as reliable and serviceable a terminal as any, it having the additional advantage of being far cheaper than any of the others. The directions for making these, together with the description of all material, are given in the following specifications, which are those of one of the leading Bell companies.

POT-HEAD TERMINALS.

Materials.

Lead Sleeves—of unalloyed lead $\frac{1}{8}$ inch thick of the following dimensions:

For	100-pair cable ;	length,	24	inches,	inside	diameter,	3	inches.
"	50 "	"	20	"	"	"	$2\frac{1}{2}$	"
"	25 "	"	20	"	"	"	2	"

Drift out the sleeve for one-half its length until its diameter is increased $\frac{1}{4}$ of an inch.

Okonite Wire, twisted pair, red and black No. 20 B. & S. gauge, $\frac{3}{32}$-inch insulation, without braid or outside covering.

Okonite Tape, $\frac{3}{4}$ inch wide.

Paper Sleeves, boiled in paraffin just before using.

Brass Tubing—thin, $\frac{1}{2}$ inch in diameter, length $2\frac{1}{2}$ inches less than that of lead sleeves.

Heavy Cotton Twine, or wicking.

Wiping Solder, containing 40 per cent. tin.

Splicing Compound, as furnished for the purpose by the company. Do not mix the compound with other materials.

Directions.

Remove the cable sheath for fifteen inches, slip the lead sleeve over the cable, splice the cable wires to okonite wire in the usual manner, join the colored wire of the cable to the red

Fig. 326.—Cable Terminal Box with Balcony.

okonite of each pair, cover each splice with a sleeve, and keep the splices within a limit of thirteen inches from the end of the cable sheath. Remove all pieces of paper or other débris, bind the cable wires as they leave the sheath tightly with several layers of twine to prevent the compound entering the cable, tape all the okonite wires together for three inches in such a manner that one-half inch of the taped wire will be below the surface of the com-

pound. Open up the spliced wires as much as possible to allow free spaces between, bind the brass tube with twine alongside the wires with the lower end even with the end of the sheath of the cable, binding no higher than the wire splices; draw up the lead sleeve until its lower end laps over the cable sheath $1\frac{1}{2}$ inch, and wipe it to the sheath. Secure the whole in an up-

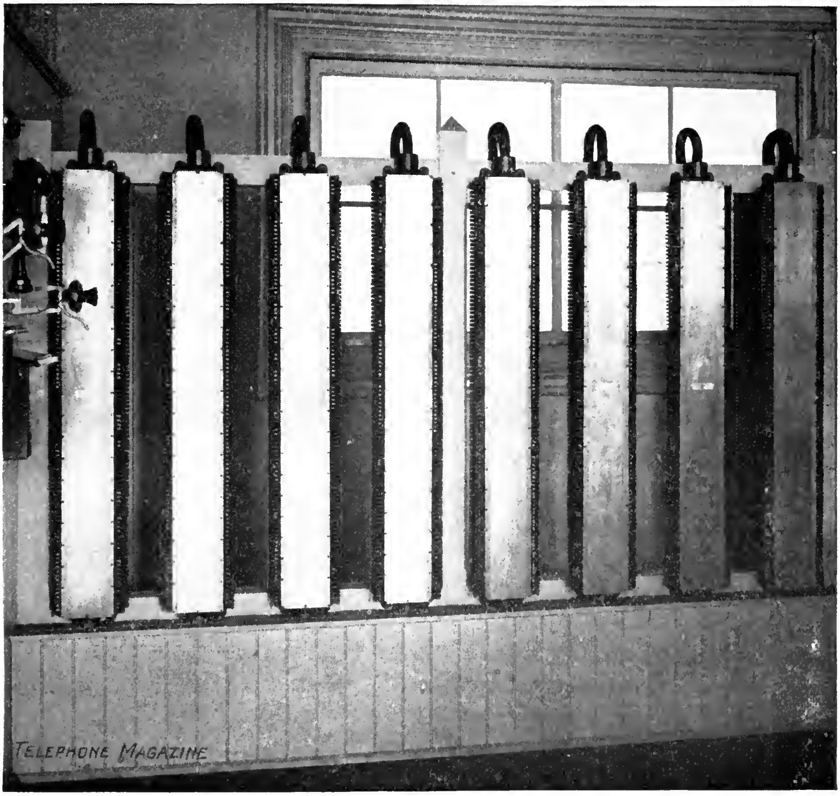


Fig. 327.—Interior Cable Heads.

right position, warm the lead sleeve until it can barely be touched with the hand, place a funnel in the brass tube, and slowly pour in the sealing mixture, previously heated to 350° F., until it fills the sleeve to within one-half inch of the top, remove the funnel and allow the compound to settle and cool. Test the compound just before using by putting in a short piece of okonite wire for two minutes. If the okonite is not softened so as to readily come off the wire the compound is not too hot. Protect the open end and the wires leading therefrom against the

weather. On the next day fill with hot compound to make up for the settlement. Three days later do the same if necessary. After this, and when thoroughly cold, dress the top of the lead sleeve into contact with the okonite tape wrapping, which at this point should consist of at least four layers. Place a cross on the outside of the lead sleeve at a point opposite the upper end of the brass tube. *Caution:* Do not boil out the cable end with paraffin. If dampness enters, the cable should not be used until this defect is remedied or the part cut away. *Under no circumstances* must paraffin be used on okonite ends.

The okonite paired wires shall project above the end of the flexible end for a distance of:

For	100 pairs	cables	3 feet.
"	50 "	"	2 "
"	25 "	"	1½ "

Cable heads, whether of the ordinary iron or the pot-head type, when placed on poles are usually inclosed in a wooden box of suitable dimensions for allowing connections with the external circuits. These boxes should be provided with hinged doors and made as nearly water-tight as possible. Directly below these boxes should be erected a balcony upon which the workmen may stand when making connections for testing the various lines. Such construction is well shown in Fig. 326.

In Fig. 327 is shown a row of eight cable terminals used in terminating as many one hundred pairs of cables within an exchange. These particular terminals are the product of the Sterling Electric Company, and are provided with combined sneak current and carbon arresters for each line.

CHAPTER XXXII.

UNDERGROUND CABLE CONSTRUCTION.

THE tendency at present is to place all telephone wires in cities underground, and the primary requisite for this construction is that a suitable conduit shall be provided in which the conductors may be laid. It is usually necessary to provide conduits having a suitable number of ducts to meet the requirements for future as well as immediate use, and much judgment should be exercised in this respect in planning the system. Suitable openings are provided for the conduits at frequent intervals, these being in the form of man-holes, from which sections of the cables may be drawn into the ducts and withdrawn when occasion requires for repairs. The principal requirements for a good conduit may be outlined as follows:

The material of which the conduit is made must be durable, and this implies that it must be absolutely proof against decay or corrosion due to moisture, dry rot, gases, or the liquids present in the soil. It should, moreover, be fire-proof if possible, although this is a minor consideration.

The conduit should possess both tensile shearing and crushing strength. Severe vertical strains are frequently imposed upon subway structures, due to the removal of the support from beneath them, caused by excavations in the streets or by the settling of the ground. Side strains are not so likely to occur, and their effects are usually slight; therefore, it follows that the conduit should be, if possible, strongest in a vertical direction. If the stress imposed upon the structure is such as to cause a fracture or undue settling, the alignment of the ducts is thereby destroyed, which may interfere with the drawing in or withdrawal of cables. Moreover, the grade of the duct is destroyed, so that the proper drainage cannot be effected. The ducts between man-holes should be straight if possible, and where curves are necessary they should be very gradual and present no sharp corners which would interfere with the drawing in or seriously abrade the cable sheath. Slight turns in conduits are frequently made by joining together short straight sections, but where the nature of the conduit used permits it, it is better to form all bends of

curved sections. It is desirable that the structure should be composed of insulating material and be moisture-proof. No dependence, however, for insulation of the conductors themselves must be placed on the conduits, as the cables must in all cases provide the means for keeping the conductors thoroughly insulated and free from moisture, even under the most adverse circumstances. Even the most perfectly constructed conduits cannot be kept dry, on account of the sweating of their interior walls.

It is very essential that the conduit must contain no chemical agents capable of exerting a deleterious effect on the cable sheath. As an example of this may be mentioned certain forms of wooden conduits, which in the process of decay liberate acetic acid, which in a short time totally destroys the cable sheath, changing it to lead acetate. This difficulty has been experienced with some forms of creosoted wood conduit, but in the later products in this line this difficulty is said to have been completely removed by the use of a better grade of creosote oil and improved methods.

Economy of space is often an important item in the selection of conduit to be used, and under crowded conditions that conduit which will place a given number of ducts within the smallest space is the most desirable, other things being equal.

The earliest form of conduit used in this country was the open-box conduit, which consisted merely in a trough made of inch-and-a-half or two-inch lumber and of sufficient size to accommodate enough cables to meet the existing demands, as well as the future growth of the system. These troughs were laid in a trench, the bottom of which was properly graded, the sections of the trough being about fifteen feet in length and butt-jointed—that is, laid together end to end. The joints were held in line by boards nailed on the outside and overlapping each end about a foot. The cable was laid in these troughs by driving the reel containing it slowly alongside of the trench, the cable being carefully laid as it was unwound from the reel. After all the cables were in place the trough was filled with hot pitch, when the cover was nailed in position and the trench refilled. This is probably the simplest form of underground cable construction, with the exception of a method sometimes practiced in Europe, of laying the cable directly in the ground without any conduit whatever.

The cheapest and simplest form of conduit which permits the drawing in or withdrawal of the cables is that composed of creosoted wood tubes, or "pump logs," as they are commonly

and appropriately termed. These are usually made in eight-foot lengths, having a square external section $4\frac{1}{2} \times 4\frac{1}{2}$ inches, with a 3-inch bore. A tenon joint one-and-one-half inch long is used for securing proper alignment of the joint. Several views of this tube are shown in Fig. 328. The wood is treated with creosote or dead oil of coal tar in the following manner: The lumber is laid on cars and run into a large steel cylinder six feet in

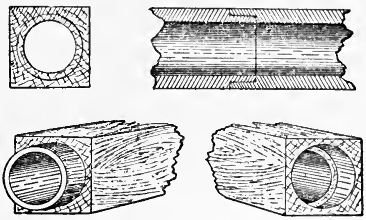


Fig. 328.—Creosoted Wood Conduit.

diameter, which is closed by a heavy iron door. It is first subjected to live steam at a temperature of 250° F. until the timber is heated through and through, the purpose of this being to coagulate the albumen in the sap. A vacuum pump is next applied to the tank, exhausting all air and steam, the pump maintaining a vacuum of about twenty-six inches. This evaporates practically all of the sap and water from the wood, thus seasoning the timber. The next step in the process is to pump creosote oil previously heated to a temperature of 100° to 125° F. into the tank until it is full. This is then placed under a pressure of about eighty pounds per square inch and the amount of creosote which is forced in after the filling of the tank is carefully measured, this being the amount that is taken up by the pores of the wood. Specifications for the treatment require that from eight to twenty pounds of the oil shall be absorbed by each cubic foot of timber. Twelve or fifteen pounds is the average amount required for electrical purposes. As has been stated before, much trouble has existed owing to the liberation of acetic acid from conduit treated with creosote. It is claimed, however, that by using a proper quality of creosote oil, and by using the method of impregnation just described, that this trouble has been entirely eliminated. The life of creosoted wood conduit is, to say the least, problematical, but there seems to be good reason to believe that when properly treated and laid it will last an ordinary lifetime, if not longer. In laying this conduit the trench is dug to a

sufficient depth, and after its bottom is properly graded so as to have a gradual slope either from an intermediate point toward both man-holes or an uninterrupted slope from one man-hole to the other, a creosoted wood plank two inches thick is laid as a foundation. The ducts are then laid on this plank side by side and in as many different layers as are necessary to give the required number. They should be so laid that the separate ducts break joints in order to give strength to the entire structure. Over the upper layer is then laid another creosoted wood plank two inches thick, after which the trench is filled in with earth. The great point in favor of this conduit is its cheapness, this being greatly enhanced by the fact that no concrete is employed for a foundation.

Conduits of clay or terra-cotta, burned hard and with vitrified surface, are being extensively used and are giving unqualified satisfaction. These are made up in a number of forms which may be divided into two classes, namely, multiple duct and single duct. The multiple-duct conduit is made up in a variety of ways, some of which are shown in cross-section in Figs. 329, 330,

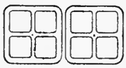


Fig. 329.—Multiple Duct Conduit.

and in the upper portion of 331. The sections of conduit shown in Fig. 329 usually have a cross-section 10 x 10 inches and a length of three feet. Similar tiles are frequently used having six or eight ducts, each about $3\frac{1}{2}$ x $3\frac{1}{2}$ inches square, the tiles varying from three to six feet in length. Frequently the ducts are made large enough to accommodate several cables, but this has a decided disadvantage, owing to the fact that much trouble is experienced in withdrawing cables under these conditions. The successive lengths of these tiles are joined by wrapping them with burlap previously dipped in asphalt. This makes the joint tight, maintains its alignment, and prevents entrance of dirt during subsequent operations.

The conduit shown in Fig. 330 is valuable only where multiples of four ducts are required. Each tile is essentially a trough, open on top and having three intermediate partitions, thus forming four ducts, each of which is $3\frac{3}{4}$ inches wide by four inches high, the walls being one inch thick. These are made in two-foot lengths, and are laid in concrete as shown, one section being laid directly on top of another until the required number of layers are

formed. The top of the upper section is composed of a sheet of mild steel of No. 22 B. W. G., having its edges bent down so as to lap over the sides of the tile.

The tile shown in the upper portion of Fig. 331 was designed by Mr. H. W. Johnston of St. Louis for the purpose of distribut-

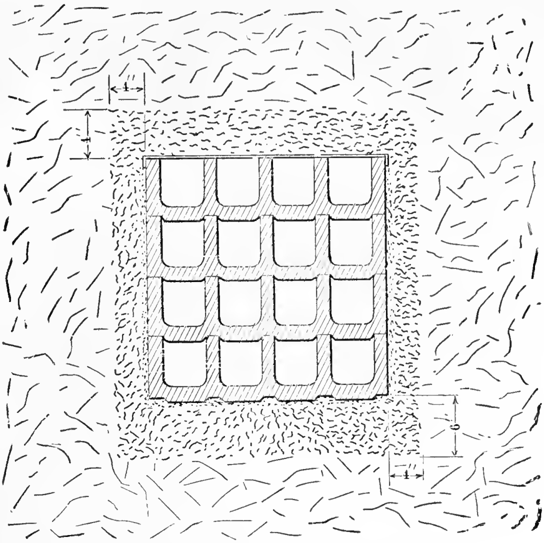


Fig. 330.—Four-Duct Terra-Cotta Tile.

ing the wires from the main cable, running to a certain section, to the various lateral ducts. The lower central duct is for the main cable running to the man-hole at the center of distribution. From this it branches out through a junction box to the distributing wires, the two four-inch openings on either side being for

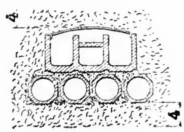


Fig. 331.—Johnston Distributing Duct.

these wires or cables, which are led out through holes in the side wall of the duct to the lateral ducts, consisting of three-inch iron pipe. The upper central duct is for rodding and drawing in of additional wires in the side ducts. A runner is drawn through the central upper duct with arms projecting over the side ducts, and by means of these projecting arms new wires may be drawn

into the side duct without in any way disturbing those already in place.

The single-duct class of tiles possesses some advantages over the multiple-duct tiles, chief among which are the greater flexibility and the increased ease of handling. The form shown in Fig. 332 has come into very wide use and has proven its adaptability

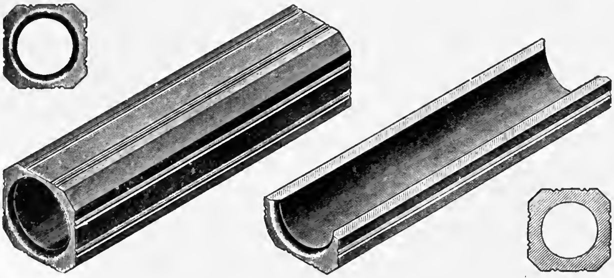


Fig. 332.—Single-Duct Conduit.

to meet almost any conditions that may arise. These tiles are $4\frac{5}{8}$ inches square by 18 inches long, and have a $3\frac{1}{4}$-inch bore. By it curves are easily made, short curved lengths being provided, or curves of long radius may be made with the regular tiles, the lengths being so short as to form a practically smooth interior surface. This conduit is laid in much the same way as ordinary brick, and in order to insure proper alignment a mandrel (Fig. 333), three inches in diameter and about thirty inches long, is laid in

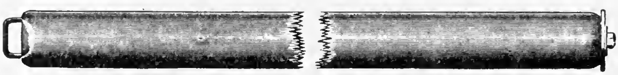


Fig. 333.—Mandrel.

the duct and pulled along through it by the workmen as each additional section is laid on. The rear end of this mandrel is provided with a rubber basket a little larger than the diameter of the conduit, which effectually smooths the inner surface and prevents the formation of lips which might prove injurious to the cable sheaths in drawing in. On the front end of the mandrel is provided an eye which may be engaged by a hook carried by the workmen in order to move it forward. Fig. 334 is a photograph showing a 48-duct subway in process of construction. In laying vitrified clay tile of any description the process to be used is as follows: The trench is dug to such a depth as to allow at least two feet of earth above the top of the entire structure. Some

specifications call for as great depth as three feet, but this is necessary only where there is a probability that new ducts may be added to the conduit in the future. The width of the trench should be at least eight inches in excess of the actual width of the number of ducts which are to be laid side by side. In the bottom of the trench is laid a concrete foundation to a depth of from three to six inches—four inches is under ordinary circumstances sufficient. The tiles are then laid in place in cement mortar, and as each layer is finished the sides of the trench should

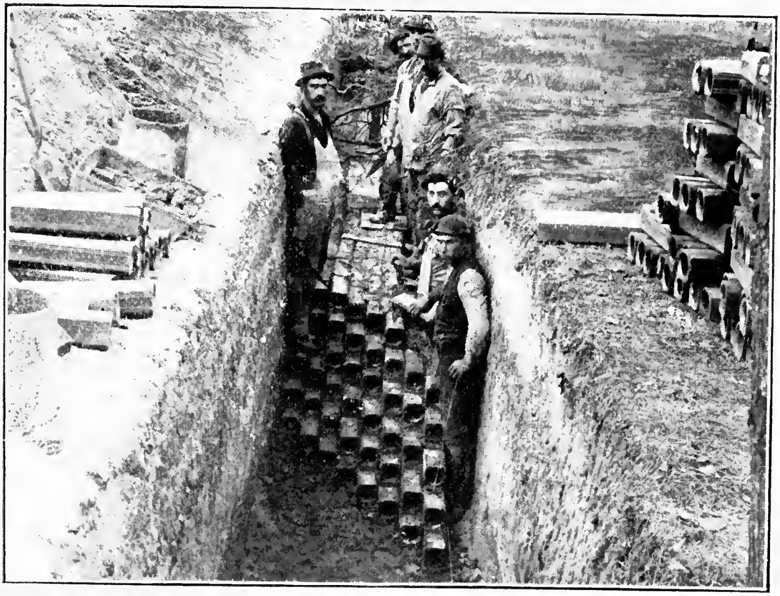


Fig. 334.—Forty-Eight Duct Subway, Cleveland, Ohio.

be filled to the top of that layer with the same concrete as that used for the foundation. The space between the tiles in a layer and between the layers should be carefully filled with good cement mortar mixed thin enough to readily fill the interstices. After the required number of layers are in place the top is covered with a mass of concrete not less than four inches in thickness.

The concrete used in this work should be composed of one part of hydraulic cement, two parts of clean sharp sand, and five parts of broken stone, screened gravel, or broken brick. The size of the broken stone or brick or gravel should not be larger than one inch in any dimension. The cement and sand should be thoroughly mixed while dry, and then enough water added to form a soft

mortar, after which the broken stone should be thoroughly mixed in.

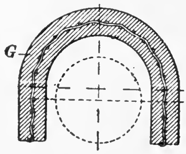
The mortar should be composed of one part of hydraulic cement and two parts of clean sharp sand, thoroughly mixed together, and then with water as before. It is a matter of greatest importance that the ducts should not be moved while the mortar or concrete is setting.

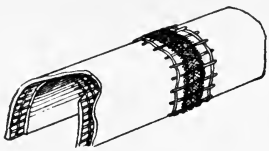
After the entire subway is laid from one man-hole to the other it is advisable to draw through it a scraper, thus removing all projections on the inside walls. The ducts may then be washed out with a hose, thus removing all grit and leaving a clean, polished tube.

Another style of conduit is the cement line pipe, which has also proven itself to be thoroughly reliable in all respects. This, as usually constructed, consists of a wrought-iron pipe of No. 26 B. W. G., with riveted joints, the rivets being set one and one-half inch apart. This pipe is lined with Rosendale cement, the thickness of the lining being five-eighths of an inch, and the interior of the lining being polished. The standard size of this tube is in eight-foot lengths, with a three-inch bore. It is provided with cast-iron ball and socket joints at the ends in order to insure proper alignment and to provide a certain amount of flexibility in making turns.

This conduit is laid in concrete in much the same manner as the clay pipe, it being common practice to separate the different pipes in the layer by about one-half of an inch and the various layers themselves by about one inch.

Another form of conduit, radically different from all those so far described, is the Sewall cement arch conduit, which is a recent production, but which gives great promise of success. The cross-section of a single duct is shown in Fig. 335, while in Fig. 336 is





Figs. 335 and 336.—Cement-Arch Conduit.

shown in perspective the method of joining two lengths. The separate ducts are formed of cement molded around a strip of wire gauze, as shown in Fig. 335. The arch is made of equal parts of Portland cement and sand, being strengthened by the metal gauze, which is made from No. 19 B. & S. gauge iron wire, woven with a mesh three-eighths of an inch square. The

inside measurement of the standard size is three inches wide and three inches from the top of the arch to the base. In laying these arches the trench is dug in the usual manner and a concrete foundation laid. The top of the foundation is made smooth to grade, being troweled to a polish. The arches are then wet and placed on the floor so formed under a templet which gives them accurate alignment. Joints are made by abutting the sections end to end. Over the joint is placed a wire gauge bridge, as shown in Fig. 336, the wire being lined inside with cotton cloth, to which is cemented a similar cloth upon the outside. As the arches are accurately molded, and as the floor is supposed to be perfectly plain, the joints so formed present a smooth interior. As soon as the first tier of arches is in position it is immediately covered with concrete, which is then smoothed down to form a second floor, upon which the second tier of arches is laid. After the required number of ducts are in place, the usual

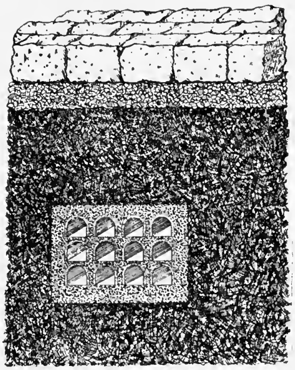


Fig. 337.—Twelve-Duct Cement Arch Conduit.

layer of concrete is placed over the entire structure. In Fig. 337 is shown a sectional view of a 12-duct conduit of this type.

Curved sections of these arches are made for making bends, these curves usually being made in 6-inch lengths. The cross-section of the duct in this conduit possesses some advantage over the round duct. If foreign matter finds its way into the duct after the cable is in place, or if a piece of the external braiding from a cable sheath is torn off, it will not be so likely to bind the cable in drawing it out as in the circular form of duct, because the foreign matter will be likely to sink down in the lower corners of the duct, where considerable room is provided for it.

In laying conduit in city streets numerous obstructions are

met, and must be overcome in the manner best suited to the individual case. It frequently becomes necessary to remove the support from heavy pipe lines for a considerable distance, as, for instance, when such a pipe line lies diagonally across the trench. In all cases suitable supports for these pipes or other structures should be provided until such time as the trench is again filled.

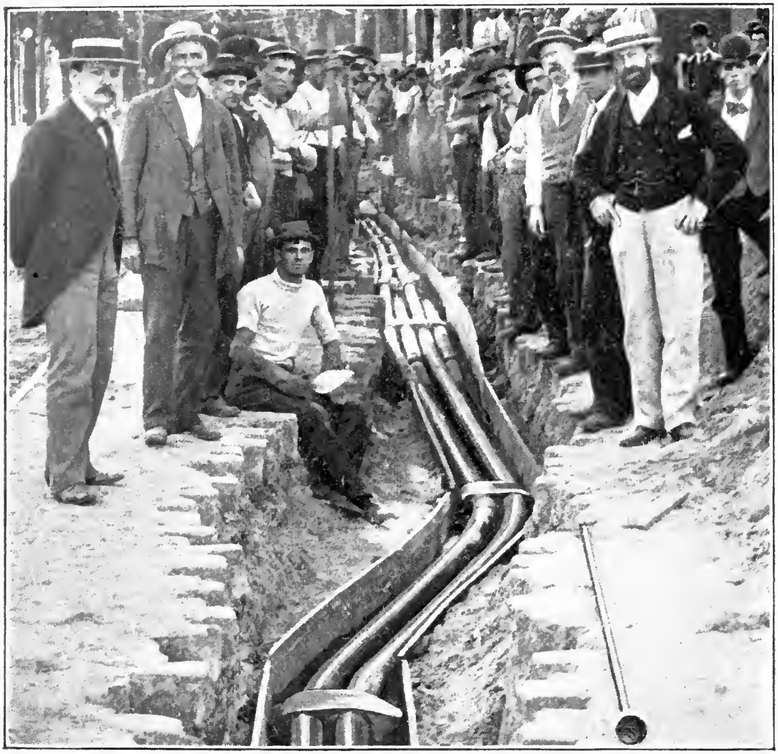


Fig. 338.—Avoiding Obstacles.

The usual means adopted is to place a beam of sufficient strength across the top of the trench and support the pipe therefrom by chains or heavy rope. It is frequently necessary in passing an obstruction to fan out the pipes in one layer so that they occupy the same level as those of another layer. Such a construction, and also a rather crooked piece of conduit work, is shown in Fig. 338, where, on account of obstructions in the street, the two layers of two pipes were formed into one layer of four until the obstructions were passed. This par-

ticular obstruction was a sub-cellar extending out under the street.

The man-holes may be built of various forms and dimensions to meet existing requirements. In the best construction the foundation consists of a layer of concrete six inches deep, the concrete being mixed as specified for the laying of tiles, with the exception that the crushed stone may be considerably coarser. The walls of the man-hole are then built of good brick-work of suitable thickness and well plastered on the outside with cement mortar in order to exclude as much dampness as possible. For the ordinary man-hole an eight-inch wall is sufficiently thick, but in building very large underground vaults it sometimes becomes necessary to double or triple this thickness. Where these very thick walls are required it is good practice to allow about one inch air space between the outer course of brick and the inner in order to render the interior as dry as possible. A common-sized man-hole is five by five by five feet, and smaller sizes down to three by three feet with five feet head room are also common. As a rule a man-hole should provide at least enough room for two men to work in conveniently. Of course, where a great number of ducts enter a man-hole the size must be increased accordingly.

After the conduits are laid and the man-holes finished the next step is the drawing in of the cables. In order to accomplish this a process called rodding is in most cases first necessary, in order that a rope may be stretched through the duct, which is afterwards to be used for drawing in the cable itself. For this purpose a large number of wooden rods about three-fourths of an inch in diameter and four feet long, and equipped with screw or bayonet joints at each end, so that they may readily join together, are necessary. A man stationed in one of the man-holes inserts one rod into the duct, and, after joining another rod to it, pushes this also into the duct. Successive rods are joined and pushed through until finally the first rod reaches the next man-hole. A rope is then attached to one end of the series of rods, which is then pulled through, disjoining the rods as they are taken out of the duct. Where the ducts are smooth and comparatively straight this process may be simplified by using a continuous steel wire about one-fourth of an inch in diameter in place of the rods. It is a good plan to attach to the forward end of this wire a lead ball, which will facilitate it in riding over obstructions. The cable reel is then placed near one of the man-holes in such manner that the cable will

pay out from the top of the reel instead of from the bottom. The end of the cable is then attached to the rope and started into the duct. In the distant man-hole the rope is led over one or more sheaves suitably arranged on upright beams placed within the man-hole to a capstan or other form of windlass by which the cable may be slowly drawn through the duct. A funnel-shaped shield should be placed at the mouth of the duct into which the cable is being fed for protecting the sheath against the sharp corners at the entrance. This shield, however, is not a sufficient protection for the cable, and one or more men should be stationed in the man-hole for guiding the cable into the duct. The best way to attach the rope to the end is by means of clamps especially provided by the cable companies for this purpose. However, if these are not used, a secure grip may be had upon the cable end by winding several strands of stout iron wire in opposite directions about the cable sheath for a distance of two feet from its end. An eye may be formed in this wire opposite the cable end, to which the rope may be attached. Particular attention should be paid to the sealing of the cable end before it is drawn into the

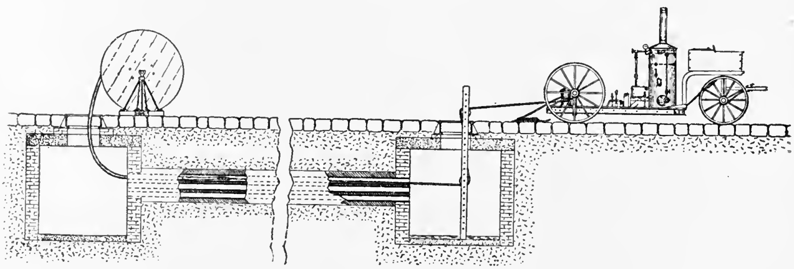


Fig. 339.—Drawing in by Steam Power.

duct, as ducts are always moist, due so sweating of the interior walls.

Where a large amount of cable is to be drawn in the method shown in Fig. 339 may be employed. Instead of the hand-operated winch or windlass a three-and-one-half horsepower horizontal engine and capstan mounted on a low wagon is used. By suitable gearing the engine causes the capstan to revolve slowly. This method, so far as the writer is aware, has been used in but one case, that being in the recent extensive underground construction work in St. Louis by the Bell Telephone Company of Missouri. It is said that with this contrivance a speed of twenty-five feet of cable per minute is easily attained without in any way damaging the cable, and the remarkably

short time in which the enormous amount of cable installed by that company was drawn in testifies further to the practical value of this scheme.

Cables, in passing through man-holes, should be laid around the side of the man-hole and supported on hooks provided for that purpose. Shields formed of sheet lead or of heavy felt should be placed under each cable just at the point where it emerges from the duct, in order to prevent injury of the sheath at that point. Workmen should be cautioned against needlessly bending cables while working in ducts, and the use of the cables in place of ladders for climbing in and out of the man-holes should be strictly prohibited.

As much slack as possible should be left in the man-hole, in order to allow room for subsequent splicing when necessary. Trouble is frequently experienced, due to the presence of gas in the man-hole, and care should always be exercised before striking a match or taking a torch into a man-hole, to make sure that all gas has been removed. There are several methods of doing this, one of which is to pump the gas out with an inverted umbrella made specially for the purpose. The umbrella is lowered into the man-hole while closed and then suddenly withdrawn, this opening the umbrella and lifting out the gas. Another way of clearing man-holes from gas is to place a cloth screen above the man-hole and on the side opposite to that from which the wind is blowing. The wind on striking the screen is deflected downward, thus causing an eddy which removes the gas from the man-hole. Very serious explosions have been caused by the formation of gas in man-holes, which becomes ignited either by an electric spark or by the torch of a workman.

One of the most serious difficulties in connection with underground cable work is that brought about by electrolysis, due to the action of stray earth currents, usually due to the ground return of electric railways. It is found that the electrolysis occurs at points where a current flowing along the cable sheath leaves the sheath and enters the ground. At this point oxygen is liberated which, with the chemicals in the earth, rapidly corrodes lead sheaths. Of course, the construction of high-class conduits, composed of insulating material, has done much toward the alleviation of this trouble. Frequent tests should be made, however, on all cable systems to determine the polarity of the cable sheaths with respect to surrounding conductors. The tests for this purpose may be made as follows: Two brass rods about six feet long should be provided, each having a steel

contact point at one end. Between these two rods should be connected by flexible wires a portable voltmeter—one reading to five volts will usually be found most suitable. The test should be made at the man-holes, these being the only available points for reaching the cable. One of the steel contact points should then be placed in firm contact with the cable sheath and the other into contact with any water or gas pipes which run through the man-hole, and in each case the voltage should be noted, not only in amount but in direction. Reading should also be taken between the cable sheaths and the rails of adjacent electric railroads, and to whatever underground structures exist in the immediate vicinity. It is evident that where the cable sheaths are negative to the surrounding conductors no danger will exist, as this would indicate that the current tended to flow through the other conductors to the sheath. If, however, the cable is found positive to the surrounding conductors, the matter should be carefully followed up by taking readings in successive man-holes. By these means the maximum danger point can be located, it being, as a rule, the point at which the maximum positive difference of potential exists. At this point the cable sheath should be securely bonded by a heavy conductor to the water or gas pipe or to other metallic structures that are in the vicinity. These bonds serve to allow the current to flow from the cable sheath to the other conductors, instead of forcing it to find circuit through the ground or through the walls of the conduit. In some cases the only remedy has been to run separate return circuits from the maximum danger points on a cable directly to the power-house from which the troublesome current emanates. All of the cable sheaths entering a man-hole should be bonded together, the usual method of doing this being to brighten the surface of the lead sheaths and to bend a No. 10 B. & S. copper wire around each sheath, afterwards soldering the connection. This assures the fact that all of the cable sheaths will be at an equal potential and that whatever bonds are run for the protection of one sheath will afford protection for all. The method of bonding to a gas pipe usually adopted is as follows: The surface of the pipe is brightened for a space of about three by eight inches with a coarse file. This surface is then heated by a torch and tinned with ordinary solder. A copper plate about three by seven inches previously tinned is then soldered to the gas pipe, after which the bond wire leading from the cable is wound into a flat coil and soldered to a copper plate.

In bonding to a water pipe it is impossible to heat the pipe sufficiently to make it take solder on account of the water flowing within. The method to be followed is to provide a heavy wrought-iron U-shaped band adapted to fit snugly around the pipe. The ends of this band are screw-threaded and pass through a yoke-piece bent to fit the upper portion of the pipe. This yoke-piece is then firmly screwed in place by nuts, the surface of the pipe and the interior of the iron clamp having previously been thoroughly brightened. The bond wire may then be soldered to this yoke-piece and the whole device smeared with asphalt paint.

CHAPTER XXXIII.

TESTING.

TESTS of telephone lines, whether of bare wire on poles or of overhead or underground cables, may be divided into two general classes:

First: Those which are for the determination of the existence of certain conditions, without the necessity of measuring quantitatively the extent to which those conditions exist; in other words, rough tests for the determination of grounds, crosses, or breaks, usually made with instruments such as the magneto-bell, telephone receiver and battery, and a few other such simple but often in the hands of an experienced person most effective instruments.

Second: Those for not only determining the existence of certain conditions, but also for their quantitative measurements. These require the use of different and more intricate instruments, and in many cases the operator must be possessed of a fair degree of mathematical training combined with an ingenuity for meeting and mastering unusual problems that arise under different conditions.

The magneto testing set is the most important instrument in making tests under the first class. Such an instrument usually consists of a powerful magneto-generator so wound as to enable it to ring its own bell through a resistance of from 25,000 to 75,000 ohms. A powerful magneto-telephone is carried on the outside of the case in suitable clips, and may be switched in circuit alternately with the generator by a small hand switch. This magneto-telephone serves as both transmitter and receiver, and enables the lineman or other party to communicate from a pole top or man-hole with any other party on the circuit. Frequently these sets are made to include microphone transmitter and battery; but, inasmuch as the instrument is seldom if ever used to talk over very long circuits, the extra weight of these is considered in most cases undesirable. A small, inexpensive galvanoscope or current detector will also prove very convenient.

In testing for a ground on a wire, whether it be in a cable or bare, and on poles, make sure that the far end of the line is open

and then connect one terminal of the magneto-bell to the near end of the line and ground the other terminal. The ringing of the bell would seem to indicate that the circuit was complete and the line grounded in this case, but this is not always true, and this test must therefore be relied on only with caution. The static capacity of a long line or of a comparatively short length of cable will often allow enough current to pass to and from the line in charging and discharging to ring the magneto-bell.

For testing out local work where there is no room for this capacity effect, the magneto-bell is invaluable.

A more reliable means of making tests for grounds or crosses is to connect the current detector in series with several cells of battery and to ground one terminal. Then with the other ter-

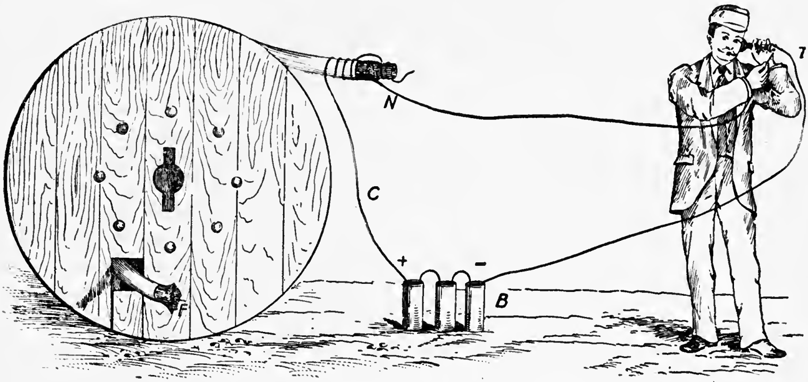


Fig. 340.--Receiver Test for Crosses and Grounds.

minal make contact with the near end of the line. A kick of the needle will take place in any event on closing the circuit, due to the current flowing to charge the line, but a permanent deflection will indicate a ground.

In testing for a cross, as for instance with some other wire in the line or cable, one terminal of the magneto-bell or the galvanoscope and batteries should be connected to the wire under test and the other to all the other wires in the same lead, for which purpose they are bunched. In case it is not convenient to bunch them, however, the test may be made between the suspected line and each of the others in succession.

Another and perhaps still more simple method for determining a cross or ground is one described in Roebling's pamphlet on Telephone Cables, and illustrated in Fig. 340, as applied to the testing of a cable before it has been unreeled.

N represents the near end, and *F* the far end of the wire being tested. *B* is a battery, of about three cells. *T* is an ordinary telephone receiver. The wire, *N F*, is carefully separated from all the others at each end.

At the near end all the wires are stripped of insulation and, except the one under test, are connected together and also with the sheath. The wire, *C*, connects the sheath to one side of battery, *B*, and the other side of battery is connected to one side of telephone receiver, *T*. The testing man rapidly taps with the wire, *N F*, the unoccupied binding post of the receiver, *T*. The first tap will produce in the receiver a distinct click, and if the cable is long there may possibly occur a second faint click, but if the wire, *N F*, is perfectly insulated, no more sound in the telephone will follow the tapping. If, however, the wire, *N F*, is crossed with any wire in the cable, or with the sheath, every tap will be followed by a distinct click, and if there is moisture in the paper, making a partial connection, clicking sounds will occur, which are loud or faint, according to the amount of moisture present.

The philosophy of this method of testing is very simple, and serves to make the operation more readily understood.

When the wire, *N F*, is first connected to the battery, it becomes charged. During the process of charging a current flows into the wire and passes through the coil of the receiver and causes the click. If the wire is well insulated, the second tap, immediately following, finds it charged, or nearly so, and there is, therefore, no click, or a very faint one. If, on the contrary, the wire under test is crossed with any of the other wires, or imperfectly insulated from them, or from the sheath, the wire will immediately discharge itself through the cross to the other wires and the sheath, and there will be a flow of current at every tap, and consequently a continuous clicking. If a conductor in a perfectly insulated cable is very long, two or three taps or a long first contact may be necessary to charge it completely.

If the cable is in place or if it is a bare aërial line that is being tested this same method may be used. In case of a new cable it is well to test every wire in this manner, and therefore the wire, *N F*, should be put aside and another slipped out of the bunch and tested in the same way, and so on until all have been gone over.

If any of them are found to be in trouble, it is well to carefully inspect the exposed ends to be sure they are properly cleared from each other and from the sheath. If it is still found to be defective, it should be plainly tagged.

In the manner just described, twenty-five minutes with two men should be ample time for testing one hundred wires, the testing operator listening and his helper attending to the connection of the different wires at *N*.

For this test as well as many others it is very convenient to use a regular operator's receiver and head band, as it will save the tester a very tired arm at the end of a long test. As a matter of fact, the receiver is little appreciated as a testing instrument. A very convenient set is formed by a watch-case receiver and head band, and two small-sized cells of dry battery, strapped together so as to be carried in the coat pocket. The receiver and battery are connected in series, the free terminals of the circuit being formed by flexible cords about four feet long. These cords should terminate in convenient clips, or contact points adapted

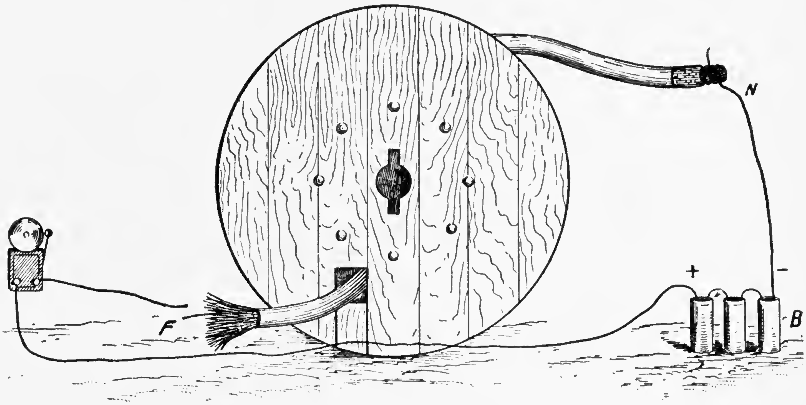


Fig. 341.—Continuity Test.

to make contact with the wires to be tested. This arrangement leaves both hands free at all times, and is wonderfully sensitive.

The continuity test, or test for broken wires, may be made with the same simple instruments. The wires to be tested should all be grounded or connected to a return wire at the far end. At the near end, one pole of a magneto-bell, or of the battery and galvanoscope, or of the receiver, should be connected to ground or the return wire and the other terminal connected successively to the terminals of the line, which, of course, should all be separated. A ring in the case of the magneto, or a permanent deflection of the needle in the case of the galvanoscope, or a continuous clicking in the receiver, will indicate that the wire is continuous. The same precaution as previously pointed out must, however, be

observed with the magneto-bell. This same test for continuity is well illustrated in Fig. 341, in which case a vibrating bell instead of the receiver or galvanoscope is used.

In testing a cable all defective wires should be marked "crossed," "grounded," or "broken" at the end at which they are tested. The corresponding ends of the tagged wires at the other end of the cable should then be found and similarly marked. If there are not the requisite number of good wires in a new cable it should be rejected.

Lead-covered cables, manufactured by reliable firms, are always subjected to a much severer test than it is possible for the purchaser to give them before they leave the factory. It is therefore considered by many as unnecessary to make a test on new cable on reels, purchased from reputable firms, unless some injury in shipment is suspected.

It is often desirable to be able to pick out a certain wire at some intermediate point in an open cable, or in a large bunch of insulated wires, in order to establish a branch connection. This is easily done by the foregoing methods if the cable is to be cut, but frequently this is not the case. It may be done without cutting by the following simple method: Ground the wire or wires desired at the distant end, being sure that these wires are free from all the others at both ends. Then having loosened the bunch of wires at the point at which the branch is to be taken off, test each by means of a needle-pointed instrument, connected to ground through a bell or receiver and battery. The needle-point can readily pierce the insulation and make good contact with the conductor within. A knowledge of this very simple test will often save an immense amount of trouble.

In the second class of tests—that is, those requiring quantitative measurements—there are three distinct subdivisions, which are as follows: Tests for resistance or conductivity, tests for capacity, and tests for insulation. Tests for the location of faults in lines always depend on the application of one or more of these.

There are three principal methods of making resistance tests: First, by the use of a Wheatstone bridge, which is accurate for all resistances except those very large or those very small. Second, the fall of potential method, which is of value in measuring very small resistances, as of a large conductor, such as a trolley-wire or heavy feeder. This method has little use, therefore, in telephone work where all conductors are comparatively small. Third, by the use of a sensitive galvanometer in series with a battery. This method is the most accurate for the determination of

extremely high resistances and is, therefore, of great use in measurements of insulation resistance.

For general resistance measurements the Wheatstone bridge is the most suitable, being very accurate and exceedingly simple in manipulation. In order to appreciate the possibilities of this instrument its underlying principles should be understood. In Fig. 342, A, B, R, and X represent resistances. G is a galvanometer or instrument for detecting the flow of current. The four

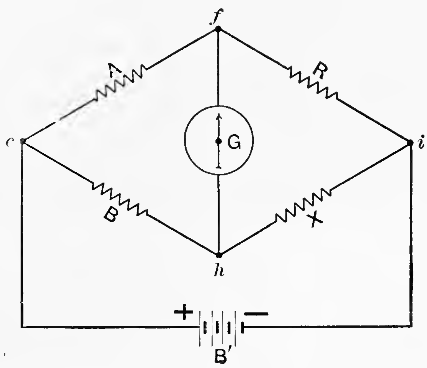


Fig. 342.—Diagram of Wheatstone Bridge.

resistances are connected together as shown, the galvanometer being connected in the "bridge" between the junctures of A and R, and B and of X. A battery, B', is connected between the junctures of A and B, and of R and X. Each resistance, A, B, R, and X, forms, what is termed an arm of the bridge.

The two fundamental laws upon which the action of the bridge is based may be stated as follows:

1. *No current will flow between points of equal potential;* and
2. *The drop in potential along the various parts of a conductor is proportional respectively to the resistances of those parts.*

Referring again to the diagram, it is evident that a current from the battery flows to the point, e, where it divides, part flowing through A R and part through B X, after which they unite and pass to the negative pole of the battery. But what of the galvanometer? Evidently by Rule 1 the only time at which no current will pass through it will be at the time when the points, f and h, are at the same potential. By Rule 2 these points will be at the same potential only when A bears the same relation to R as B does to X.

That is

$$A : R :: B : X, \text{ or, by alternation,}$$

$$\frac{A}{B} = \frac{R}{X}.$$

A little algebra will render the above evident if not so already.

Call a the drop of potential between the points e and i, f that between e and f, and c that between e and h.

Then

$$b : a :: A : A + R \text{ by Rule 2.}$$

$$\therefore b = \frac{A}{A + R} a.$$

Similarly

$$c = \frac{B}{B + X} a.$$

For a condition of equal potentials at f and h so that no current will flow through the galvanometer, b must $= c$.

Then

$$\frac{A}{A + R} a = \frac{B}{B + X} a.$$

whence: $$AB + AX = AB + BR,$$

and $$AX = BR.$$

Dividing by BX, we have

$$\frac{A}{B} = \frac{R}{X},$$

which is the equation of the ratios between the resistances of the arms of the bridge, to insure no flow of current through the galvanometer.

The resistance to be measured forms the arm X of the bridge, and in order to determine its value the resistances in the various arms are adjusted till no current flows through the galvanometer. Then the equation just derived holds good and may be solved for X,

$$\text{thus } X = \frac{B}{A} R.$$

The arms A and B are best termed the "ratio arms" of the bridge and arm R the rheostat arm.

In commercial forms of the Wheatstone bridge, A and B are usually so arranged that each may be given the values, 10, 100, and 1000 ohms, and in some cases 1 ohm and 10,000 ohms also.

The ratio arms, A and B, may therefore be adjusted to bear any convenient ratio to each other from $\frac{10}{1000}$ to $\frac{1000}{10}$, or, in some instances, from $\frac{1}{10,000}$ to $\frac{10,000}{1}$. The rheostat arm is in reality a rheostat capable of being adjusted to any value from 1 to about 11,000 ohms.

In some bridges a sealed battery is furnished with and forms a part of the instrument. In those having no battery, suitable binding posts are provided, usually marked BB, between which the battery may be connected. Other binding posts, usually marked XX, are furnished for connecting the terminals of the unknown resistance to be measured.

Two keys are usually furnished, one in the battery circuit and the other in the galvanometer circuit. Each keeps its circuit normally open.

The operation of the bridge is very simple. First some ratio between the arms A and B is determined upon. The battery is then connected between the proper binding posts, and likewise the resistance to be measured is connected between its binding posts.

The battery key is first depressed and then the galvanometer key. A deflection of the galvanometer needle will take place which by its direction will after a few trials show whether the resistance in the rheostat arm is too great or too small. The rheostat is adjusted accordingly until the galvanometer needle shows no deflection upon the operation of the keys. We then know that our equation

$$\frac{A}{B} = \frac{R}{X} \text{ holds good,}$$

and consequently

$$X = \frac{B}{A} \times R.$$

That is, *the unknown resistance is equal to the ratio between B and A multiplied by the resistance in the adjustable arm.*

Considerable judgment may be exercised in the choosing of the appropriate ratio in the ratio arm to obtain the greatest accuracy. Obviously if a very high resistance is to be measured the ratio should be large, and *vice versa.*

In bridges having resistances of 10, 100, and 1000 ohms in the

ratio arms, the following values in arms *A* and *B* will give the best results:

Resistance to be measured.	*A* arm.	*B* arm.
Under 100 ohms, ...	1000	10
100 to 1000 ohms, ...	1000	100
1000 to 10,000 ohms, ...	1000	1000
10,000 to 100,000 ohms, ...	100	1000
100,000 to 1,000,000 ohms, . . .	10	1000

As to the accuracy of measurements attainable by the use of the Wheatstone bridge, the following table represents the claim of one reliable manufacturer:

.01	of an	ohm	to an	accuracy	of 1	per	cent.
.1	"	"	"	"	" ½	"	"
1	ohm		"	"	" ½	"	"
10	ohms		"	"	" $\frac{1}{5}$	"	"
100	"		"	"	" ⅛	"	"
1000	"		"	"	" ⅛	"	"
10,000	"		"	"	" $\frac{1}{5}$	"	"
100,000	"		"	"	" ¼	"	"
1,000,000	"		"	"	" 5	"	"

If using the 110 volt lighting circuit as battery power 1 megohm may be measured accurate to ½ per cent.

There is no doubt but that with a well-made bridge with a sensitive galvanometer, these results may be equaled if not surpassed. Great care must be taken in using a voltage as high as 110, as there is danger of burning out the coils. Such high voltage should be used only in measuring very high resistances, and the ratio arms should be adjusted to give as high a multiplying ratio as possible.

A particular form of bridge which has come into extensive use in this country and which possesses several unique features is shown complete in Fig. 343 and in plan view in Fig. 344.

The various adjustments of the arms are accomplished by placing plugs in the various holes between the brass blocks arranged in rows as shown in the latter figure. Between each successive pair of blocks are arranged resistance coils having the resistances in ohms designated on the plan. Placing a plug in a hole between two blocks short-circuits the resistance connected between those two blocks. The rheostat arm of this bridge is represented by the top and bottom row of blocks, and if all plugs

are removed the resistance in this arm will amount to 11,110 ohms. The ratio arms *A* and *B* are represented by the left- and right-hand halves respectively of the center row. A galva-

Fig. 343.—Portable Testing Set.

nometer and suitable battery, together with battery and galvanometer keys, are all mounted in a carrying case as shown.

The connections of this instrument are indicated in Fig. 344,

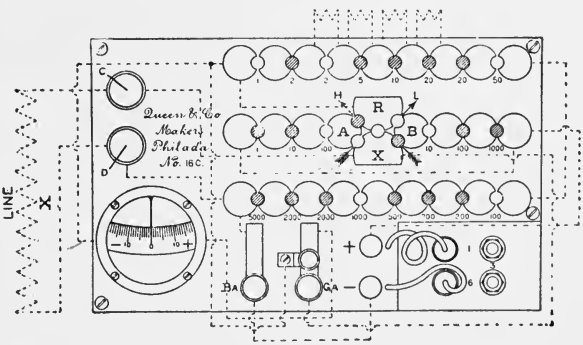


Fig. 344.—Plan of Portable Testing Set.

and are as follows: The top row of blocks is connected to the bottom row by a heavy copper bar joining the right-hand blocks. This connection is made very heavy so as to interpose no extra resistance in the rheostat. On the rheostat formed by the

upper and lower rows of blocks any resistance from 1 to 11,110 ohms may be obtained, the resistance being added by *leaving out* plugs. The lower left-hand block of the rheostat is connected to the lower binding post, *D*, forming one terminal of the unknown resistance. The upper post, *C*, forming the other terminal of the unknown resistance, is connected to block, *X*, which block is also joined to the galvanometer key. The block, *R*, is connected to the upper left-hand block of the rheostat. The end blocks of the middle row are connected together and to the + terminal of the battery. The — terminal of the battery is connected through the battery key to the lower left-hand end of the rheostat. One galvanometer terminal is connected directly to the block, *R*, the left-hand block of the rheostat, and to the back contact of the galvanometer key. The other galvanometer terminal is connected through the key to the block, *X*.

By carefully following out these connections it will be apparent that the parts as connected form three arms of a Wheatstone bridge, the fourth, of course, being the unknown resistance

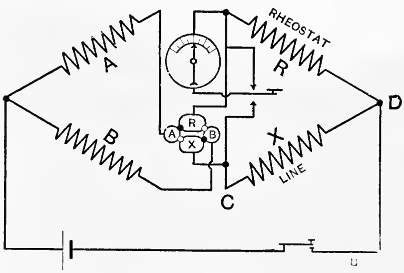


Fig. 345.—Circuits of Portable Testing Set.

joined to the line posts. This is shown diagrammatically in Fig. 345, where the corresponding parts are similarly lettered.

It will be noticed that this latter figure is practically the same as Fig. 342, with the addition of the center blocks, *A*, *B*, *X*, *R*, forming a sort of commutator. The object of this arrangement is to make it possible to reverse the connections of arms, *A* and *B*, with *R* and *X*. Thus with the plugs in the position shown by the black dots, the connection is precisely as shown in Fig. 342, and the equation $\frac{A}{B} = \frac{R}{X}$ holds true. If, however, the plugs are inserted in the holes on the other diagonal, arm, *A*, will be connected to arm, *X*, and arm, *B*, to arm, *R*, and the equation of the bridge will be $\frac{B}{A} = \frac{R}{X}$.

The bridge arms, *A* and *B*, have not the same range of resistances in this bridge, *A* having only 1, 10, and 100 ohm coils, while the resistances of *B* are 10, 100, and 1000 ohms. Therefore, if a ratio of 1000 to 1 for measuring large resistances is desired, the plugs are inserted in the commutator along the arrow *H* (Fig. 344); while an opposite arrangement of the plugs along the arrow *L* will give a ratio of 1 to 1000 for very small resistances. In this bridge the galvanometer key is so arranged as to short-circuit the galvanometer while the key is up.

The galvanometers usually furnished with the complete bridges consist of a needle so mounted as to swing freely in a horizontal plane. This needle is given a tendency to point in one direction sometimes by the action of the earth's magnetic field and sometimes by the field of a powerful permanent magnet. By causing the current through the bridge wire to flow through a coil, either stationary and surrounding the needle, or movable and carried on the needle, the needle is caused to swerve from its normal position and to place itself at right-angles to the lines of force due to the permanent field. The deflection of the needle is great or small according to the strength of the current, and to the right or left according to the direction of the current.

In many of the tests to be described later a galvanometer of greater sensitiveness is required, and some form of *reflecting* instrument is used. In these the needle carries a small circular mirror, which reflects a spot of light from a lamp or some other source against a scale. In this arrangement every movement of the needle causes the spot of light to move along the scale, and a little consideration will show that the angle through which the reflected ray of light moves is double that through which the needle travels. Thus this reflected ray of light serves as a needle of any desired length, and has the advantages of magnifying the angular movement of the needle to twice its real amount, and of possessing no mass, and therefore no inertia.

The two galvanometers used to the greatest extent for quantitative measurements in practical work are the Thomson and the D'Arsonval.

The Thomson galvanometer is made in a great variety of forms. The needle consists of several very light bar-magnets arranged side by side and with opposing poles together, so that the directive influence of the earth's field shall be very slight. The needle is directly attached to a small silvered glass mirror, and is suspended within the coil or coils by means of a silk or

quartz fiber. The current to be measured is passed through the coils, and the magnetic field set up thereby causes the needle to swerve from its normal position. The Thomson galvanometer is used in the most delicate tests, and is essentially a laboratory instrument. It has the disadvantage of being affected to such an extent by external magnetic fields as to render its use impossible in many cases. A passing street car or variations in the

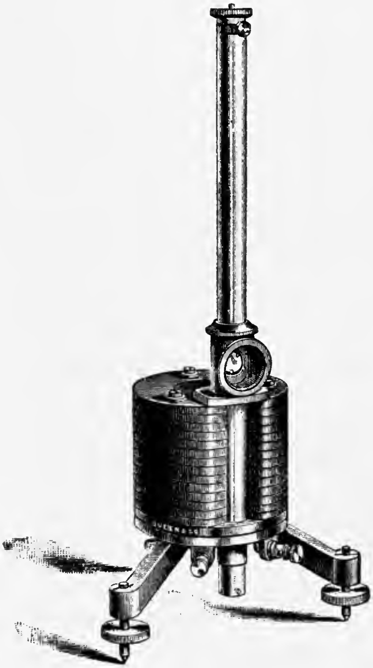


Fig. 346.—D'Arsonval Galvanometer.

current flowing in a neighboring circuit will cause the needle to swing violently, thus making accurate work out of the question. These disadvantages may be overcome to some extent by inclosing the galvanometer in a heavy iron case—such as an old safe—but they tend to make it a very undesirable instrument for portable work. Where the instrument can be permanently set up and properly guarded, it is unequaled for delicacy and accuracy.

For nearly all practical engineering work, the D'Arsonval galvanometer is sensitive enough, and has the advantage of being much more convenient for general work. In this the needle is a coil instead of a permanent magnet, and is suspended within the

field of a powerful permanent magnet instead of in a coil. The needle carries a mirror, as in the Thomson instrument. The current to be measured is passed through the coil, and as this coil lies in the field of the permanent magnet, a rotation of the coil ensues, the action being identical with that which causes the armature of an electric motor to revolve.

In Fig. 346 is shown a much-used form of D'Arsonval galvanometer made by Queen & Co., Philadelphia. The field is built up of a number of horizontal permanent magnets, between the

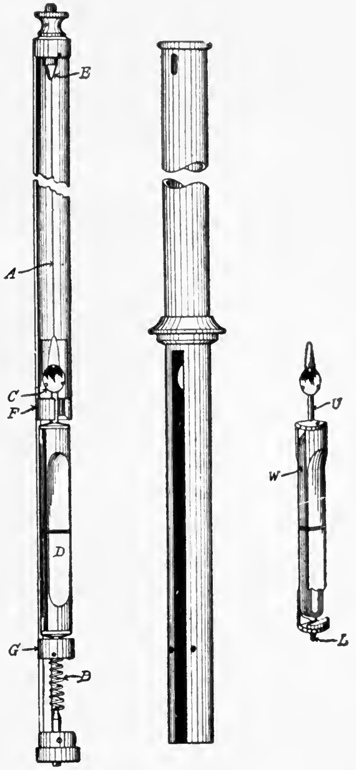


Fig. 347.—Suspension of D'Arsonval Galvanometer.

poles of which is suspended the needle. The needle system is shown in detail in Fig. 347. It consists of a coil of wire, *W*, wound on a boxwood frame, *D*, and supported by means of the flat phosphor-bronze filament, *A*, from the torsion pin, *E*. The current is led in by means of the torsion pin, *E*, and suspension wire to the coil; thence to the spiral spring, *B*, and by means of the bottom contact out to the external circuit. A ring, *F*, is

joined above the coil frame, and another, *G*, below the coil frame. These are normally a sufficient distance apart to enable the system to swing freely, but when packing for transportation the torsion head may be pressed down until the rings above men, tioned firmly clamp the coil. In this condition it will withstand shipment satisfactorily. To the right is shown the coil more clearly. The two points, *U* and *L*, have soldered to them the ends of the coil, *W*. The mirror is shown at *C*.

The great advantage of the D'Arsonval galvanometer is that it is unaffected by variations in the external magnetic field. It may even be used close to dynamo machinery without being sensibly affected.

In order to read the deflection produced by a current, in any

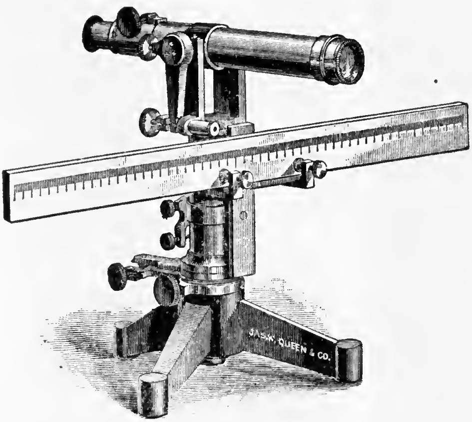


Fig. 348.—Scale and Telescope.

form of reflecting galvanometers, two methods may be employed. One is to cause the needle to reflect a spot of light from a stationary source, upon a horizontal scale, and by watching the movement of the spot the number of scale divisions deflection may be accurately determined. Another and better way is to focus a telescope on the mirror, in such manner that the horizontal scale will be visible in the telescope. The mirror in its movements will reflect different portions of the scale into the telescope, and the deflection may thus be observed with great precision. When this method is used the numbers on the scale should be reversed, in order to appear normal in the telescope. Fig. 348 shows a telescope and scale as arranged for this purpose.

Complete testing sets, containing reflecting galvanometers,

bridges, batteries, keys, and other accessories, are frequently mounted in one case, and so arranged as to fold within small compass when not in use. This arrangement is very convenient, but has one disadvantage—the manipulation of the keys and plugs jar the box to such an extent as to make the readings on the galvanometer unreliable. The separately mounted galvanometer is therefore in general to be preferred. Of course this applies only to reflecting galvanometers.

It is frequently found that a current that it is desired to measure is so large that it sends the spot of light completely off the scale, thus rendering the measurement of the deflection impossible. In order to increase the range of the galvanometer so as to make it available for measuring both large and small currents, certain resistances called shunts may be placed in parallel with the galvanometer coil as in Fig. 349. The resistance of

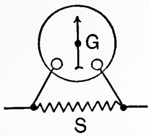


Fig. 349.—Galvanometer and Shunt.

the shunt being known, it is easy to calculate the amounts of the currents that pass through the galvanometer coil and the shunt.

Calling R_g the resistance of the galvanometer, R_s that of the shunt, I_g the current through the galvanometer, I_s that through the shunt, and I the total current through both, then

$$I = I_g + I_s.$$

Also when E is the difference of potential between the common terminals of the galvanometer and shunt,

$$I_g = \frac{E}{R_g} \text{ and } I_s = \frac{E}{R_s}.$$

$$E = I_g R_g = I_s R_s. \quad \text{Hence } I_s = \frac{I_g R_g}{R_s}.$$

Substituting this value of I_s, in the first equation, we have

$$I = I_g + \frac{I_g R_g}{R_s} = I_g\left(1 + \frac{R_g}{R_s}\right) = I_g\frac{R_s + R_g}{R_s}.$$

The quantity $\frac{R_s + R_g}{R_s}$ is called the multiplying power of the

shunt, because it represents the number by which the current through the galvanometer must be multiplied, in order to give the value of the current being measured.

Shunt boxes are usually provided for a given galvanometer with a number of coils specially arranged to give such convenient values of the multiplying powers, as 10, 100, and 1000. For this purpose the various coils of the shunt box have resistances of $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$ of the resistance of the galvanometer.

To better show this relation, assume that a multiplying power of 1000 is desired, then

$$1000 = \frac{R_s + R}{R_s}.$$

$$1000R_s - R_s = R_g.$$

$$R_s = \frac{R_g}{1000 - 1} = \frac{R_g}{999}.$$

A commercial form of shunt box is shown in Fig. 350, the various multiplying values of the shunt being obtained by plugging the block corresponding to the multiplying power desired.

Fig. 350.—Shunt Box.

For moderate deflections, the current traversing the coils of a reflecting galvanometer may, without sensible error, be taken as proportional to the deflection of the spot of light on the scale, or to the deflection read through the telescope. The current is of course inversely proportional to the total resistance of the circuit, and from this it follows that the deflections are inversely proportional to the resistance. This fact enables the galvanometer to be used for measuring unknown resistances by comparing the deflection obtained when a given E. M. F. acts through a known resistance with that obtained when the same E. M. F. acts through an unknown resistance.

The general method of measuring resistances by the use of a

galvanometer is to note the deflection obtained with a given battery and a known resistance in the circuit, and from this to compute what is called the *working constant.* This working constant may be defined as *the number of scale divisions deflection that would be obtained by causing the current from the given battery to pass through the galvanometer and a resistance of one megohm.* Of course such a deflection as this can exist in our imagination only, but it serves, nevertheless, as a convenient standard upon which to base our calculations. Having obtained the working constant, a reading is taken of the deflection produced by passing the battery current through the galvanometer in series with the unknown resistance. As the deflections are inversely proportional to the resistances, the unknown resistance is then readily computed.

If measurements of comparatively low resistance are to be made, then the resistance of the battery and of the galvanometer must be taken into consideration as well as that of the resistance placed in circuit with them, but as the measurements here considered will be those of very high resistances only, the resistance of the battery and of the galvanometer may be neglected. For the purpose of taking the constant, connections are made as shown in Fig. 351, where B is the battery, G the

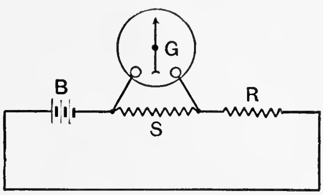


Fig. 351.—Circuits for Galvanometer Constant.

galvanometer, S the shunt, and R the known resistance. Usually the value of R is $\frac{1}{10}$ of a megohm, or 100,000 ohms. With the $\frac{1}{999}$ shunt a certain deflection will be obtained when the circuit is closed. Obviously, if the shunt were not present the deflection would be 1000 times as great, because only $\frac{1}{1000}$ of the current passes through the galvanometer. Therefore the total deflection, if it could be measured, that would be produced through the galvanometer and the 100,000 ohms resistance, would be the deflection noted multiplied by 1000. If, now, the resistance, R, had a value of 1 megohm instead of $\frac{1}{10}$ megohm, the deflection would have been only $\frac{1}{10}$ as great as this. Therefore to find the number of scale divisions deflec-

tions which the galvanometer alone would give with 1 megohm in circuit, we multiply the deflection noted by 1000 and by $\frac{1}{10}$.

In general we may say: *to find the working constant, multiply the deflection obtained by the multiplying power of the shunt, and by the value of the known resistance in megohms.*

As a numerical example let us assume that with the $\frac{1}{999}$ shunt and the $\frac{1}{10}$ megohm resistance, we obtain a deflection of 200 scale divisions, then the working constant is

$$200 \times 1000 \times \frac{1}{10} = 20{,}000.$$

In other words, 20,000 would be the number of scale divisions obtained were the entire current from the battery allowed to pass through the galvanometer with one megohm in series.

With 50 cells of battery (45 or 50 volts), the constant under ordinary working conditions with a good D'Arsonval galvanometer, will be from 10,000 to 25,000. With a Thomson instrument a much higher constant may be obtained. Mr. George D. Hale of the Western Electric Company's cable-testing department uses a large four-coil Thomson instrument with 600 volts obtained from a motor generator. With this he obtains a constant of 528,000, and by adjusting the suspension for greater delicacy can obtain as high as 2,000,000. Of course this is entirely impracticable for portable instruments, and is, in fact, unnecessary, as good work may be done with a constant of 20,000. In ordinary testing a battery of 50 cells is sufficient. Of course a higher working constant may be obtained with a larger battery, and frequently 100 cells are used.

INSULATION TESTS.

One of the principal uses of the galvanometer in line testing is in the measurement of insulation resistance. The insulation resistance of any line or conductor is the joint resistance of all the *leaks* from the line to the ground or to other conductors. On a pole line every insulator forms a leak to earth, and on a line having 40 poles to the mile there would be 40 such leaks in parallel. The insulation resistance of a line as a whole varies inversely as its length, if the insulation is uniform. Evidently, a line two miles long would have one-half as great an insulation resistance as a similar line one mile long, because on the latter there would be only half as many leaks as on the former. In

general it may be stated that a line n miles long will have only $\frac{1}{n}$ as great an insulation resistance as a similar line one mile in length. In order to obtain a standard of insulation resistance independent of the length of the line, it is convenient to express the insulation resistance as so many megohms per mile. The insulation resistance per mile is found by multiplying the insulation of the line as a whole by the length of the line in miles.

In order to measure the insulation resistance of a line the constant of the galvanometer is first taken and then the known resistance is cut out of circuit and the line insulation resistance substituted for it. Assuming that the insulation resistance to be measured is that of a wire in a cable, the terminals of the circuit which were connected with resistance, R, in Fig. 351, will be connected one with the wire and the other with the sheath of the cable as shown in Fig. 352. Care must be taken that the

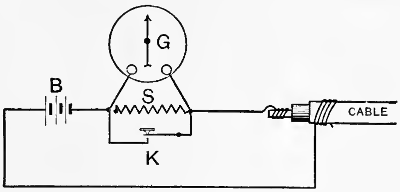


Fig. 352.—Insulation Resistance of Cable.

wire being measured is carefully insulated from the sheath at the other end of the cable. The shunt, S, is then cut out of circuit in order that the full current may pass through the galvanometer. Before completing the circuit with the cable conductor and sheath, however, the key, K, should be closed in parallel with the galvanometer, in order to prevent the rush of current that will take place in charging the cable, from causing the needle to give too violent a kick. After a short time the key is opened and all of the current diverted through the galvanometer. The galvanometer then receives only that current which leaks from the core of the cable to the sheath through the insulation. Under these circumstances a certain deflection will be noted, and by comparing this deflection with the constant already obtained the value of the insulation resistance in megohms is readily determined.

To illustrate, suppose that a deflection of 75 scale divisions is obtained with the apparatus connected as in Fig. 352. If the constant is 20,000, as already determined, we know that the

insulation resistance must be 20,000 divided by 75, or 266 megohms, thus indicating that the total insulation resistance of the cable is 266 megohms. That this is true is evident from the fact that the constant, 20,000, represents the number of scale divisions deflection that would be obtained were only one megohm in the circuit. The deflections are inversely proportional to the resistance in the circuit, and therefore the total insulation resistance is equal to the deflection through one megohm divided by the deflection through the insulation resistance, or 20,000 divided by 75. To sum up these operations:

1st. Obtain the galvanometer constant or deflection obtained when the galvanometer in series with one megohm resistance is

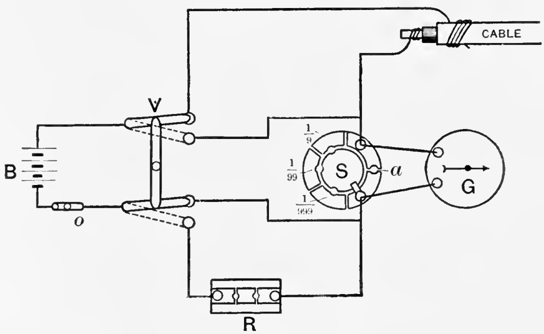


Fig. 353.—Connections for Insulation Test.

subjected to the potential of the battery. 2d. Find the deflection obtained when the galvanometer and insulation resistance in series are subjected to the potential of the battery. 3d. Divide the constant by the deflection obtained through the insulation resistance, the result being the insulation resistance of the cable expressed in megohms. 4th. To find the insulation resistance per mile, multiply the total insulation resistance by the length of the cable in miles.

If the insulation of the cable is low, a shunt must be used in obtaining the deflection through the insulation resistance. If the insulation resistance is high, the deflection will be small and no shunt will be required. The purpose of the shunt is merely to keep the deflections on the scale so that they may be read.

In Fig. 353 is shown a convenient arrangement of connections for making insulation tests. In this, *B* is the battery of say 50 cells, *R* the $\frac{1}{10}$ megohm box, *S* the shunt box, *G* the galvanometer, and *V* a convenient switch for throwing either the $\frac{1}{10}$

megohm box or the line insulation into circuit with the galvanometer and battery. When the levers of the switch, V, are in the position represented by the dotted line, the circuits are those for taking constant of the galvanometer, and when in the position shown by full lines, the circuits are those for obtaining the deflection through the insulation of the cable. Various forms of keys for changing the direction of the battery current through the galvanometer, and for performing other switching operations with the greatest possible convenience, are obtainable, and form an important part of all testing outfits. The scope of this work will not permit of their detailed description.

In making insulation tests the resistance of the lead wires to the cable or line need not be taken into account. It is a matter of the greatest importance, however, that these wires are perfectly insulated from each other. It is a very easy matter in making tests of this nature to measure the wrong quantity.

One very important matter in connection with insulation tests has not yet been spoken of. When the reading is being taken, with the cable or line insulation in circuit, it will be noticed that a maximum deflection is obtained at first, and that this gradually diminishes, as though the insulation resistance were increasing. This is due to what is called electrification, a phenomenon that is not very thoroughly understood. When the electromotive force of the battery is first applied to the cable or line, there is a sudden rush of current, due to the charging of the conductors. The charges, however, apparently *soak in* to the insulation to a slight extent, thus allowing more current to flow to the conductors. After the first rush due to the first charging of the conductors, there is still a flow of current, due in part to this *soaking in*, and in part to the actual leakage *through* the insulation. It is the current due to the latter that we are concerned with in insulation measurements, and therefore we must wait till the soaking in process ceases, when the flow of current will be practically constant, being that through the insulation. In nearly all telephone-testing work, one minute is allowed for electrification, after which the reading is taken of the deflection. When one is thoroughly familiar with his instruments he may often, where great accuracy is not required, estimate what the deflection at the end of one minute will be, by watching the deflection for 30 or 40 seconds. This method saves time, but must be used with extreme caution.

With a constant of 20,000 a reading taken on a wire in a piece of good new telephone cable, one-quarter mile long, would

probably show a deflection of 8 or 10 scale divisions upon the closure of the key. This would decrease to about 6 scale divisions in 2 seconds, and to about 2 scale divisions in 30 seconds, after which it would remain constant. The reading of 2 divisions at the end of the minute would indicate an insulation resistance of $\frac{20,000}{2} = 10,000$ megohms, or 2500 megohms per mile.

As examples of deflections on the different wires in various cables the following are given:

Dry paper cable, $\frac{3}{4}$ mile long, two years old. Galvanometer constant 22,000: Readings, 12–15–15–10–10–15–15–15–13 scale divisions.

Another dry paper cable, 2750 feet long, one year old. Galvanometer constant 19000: Readings, 5–6–5–4–5–5–5–5–6, etc.

A piece of jute and ozite cable five years old, 6000 feet long, gave the following with a constant of 20,000: 7500–2500–1000–1000–600–800–900-800–1000. It was necessary to use the $\frac{1}{19}$ shunt in taking these readings.

Another piece of the same kind of cable, 800 feet long, with a constant of 20,000, gave 175–200–250–270–160–110–120–160–110–125.

CAPACITY TESTS.

A very important measurement, especially in telephone cables, is the determination of the capacity of the line conductors with respect to all neighboring conductors. The usual method of making capacity tests is to note the deflection produced when a

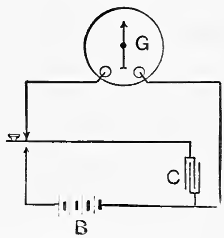


Fig. 354.—Capacity Test.

condenser of known capacity, after having been charged to a known potential, is discharged suddenly through the galvanometer, and to compare this with the deflection obtained when the cable or conductor being measured, after being charged to the same potential, is discharged through the galvanometer. The

deflections produced under these circumstances are proportional to the charges, and therefore to the capacities of the standard condenser and the line or cable. The circuits for obtaining the deflection produced by the discharge of the condenser are shown in Fig. 354, where C is the standard condenser, B the battery, and G the galvanometer. When the key is depressed the condenser is charged to the full potential of the battery, B. The key is then suddenly released, thus allowing the charge from the condenser to pass through the galvanometer, thus producing a certain throw of the needle. The connections are then made as shown in Fig. 355, the same battery, B, being used.

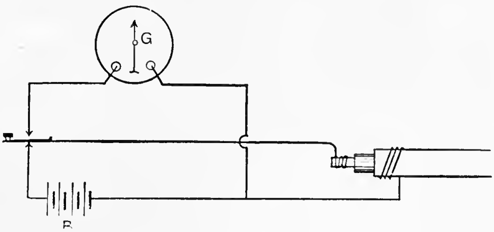


Fig. 355.—Capacity Test.

When the key is depressed the cable is charged, and when suddenly released this charge flows through the galvanometer and produces another throw of the needle. By comparing the throw produced by the charge of the condenser with that produced by the charge of the cable, a direct comparison may be made between the capacity of the cable and that of the condenser. Thus, if with the $\frac{1}{999}$ shunt the discharge from the condenser gave a deflection of 100 scale divisions, the capacity of the condenser being $\frac{1}{10}$ microfarad, and if with the same shunt the discharge of the cable produced a deflection twice as great, we would know that the capacity of the cable was $2 \times \frac{1}{10} = \frac{1}{5}$ microfarad.

Convenient connections for making capacity tests are shown in Fig. 356, where G is the galvanometer, S the shunt, C the standard condenser, KK discharge keys, V the selecting switch, and, B a battery of eight or ten cells. With the switch, V, at the left and both discharge keys depressed, the current from the battery will flow into the condenser, thus charging it. Upon the sudden release of the discharge keys, the condenser will discharge through the galvanometer and shunt, giving a deflection which should be noted. With the switch, V, at the right, the

cable may be charged and discharged in the same manner, and the deflection produced by its discharge noted. About seven cells of battery is usually sufficient for making capacity tests on telephone cables. If a non-adjustable condenser only is available, one having a capacity of $\frac{1}{10}$ microfarad is probably most desirable. For accurate work a subdivided condenser, having its divisions so arranged as to be easily connected in multiple or in series, or in combinations of the two, is very desirable. Then

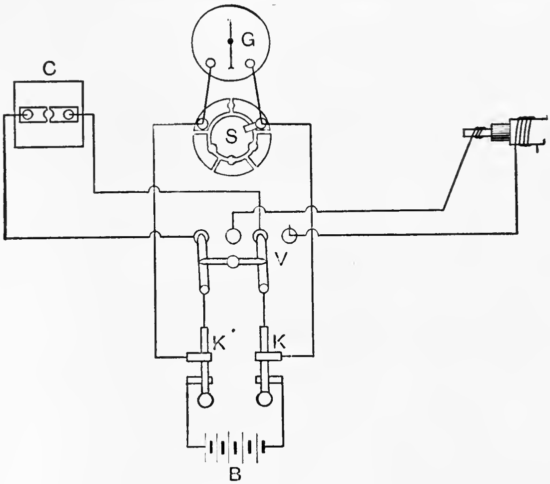


Fig. 356.—Circuits for Capacity Test.

the condenser capacity may be varied until the throw from the condenser is nearly equal to that from the cable, thus greatly minimizing the liability to error in the results. In making capacity tests the wire under test should be carefully insulated and all the other wires in the cable should be connected together and to the sheath or ground. Fifteen seconds should always be allowed for the charging of the cable.

If d is the throw due to the discharge of the condenser, d' that to the discharge of the cable, K the capacity of the condenser in microfarads, and X the capacity of the wire being measured, then

$$X : K :: d' : d$$

$$X = \frac{d'}{d} K.$$

If the throws of the galvanometer are too large to be measured, the shunt must be used. In this case d or d' in the formula will

be the actual throws observed multiplied by the multiplying power of the shunt.

THE LOCATION OF FAULTS.

When a break occurs in a wire in a line or cable, the ends remaining insulated from other wires and the ground, the only recourse is to capacity tests. The capacity of the two parts of the wire will be proportional to their lengths, the wire being uniform in size and in its relation to other wires, throughout its length.

We may locate a break of this nature in several ways.

Measure the capacity of one end of the broken wire, then go to the other end of the cable and do the same. Calling D the length of the cable in feet, C the capacity of the first portion of the wire, C' that of the other, and X the distance in feet to the break from the first end, then :

$$X : D :: C : C + C'$$

$$\text{and } X = \frac{CD}{C + C'}.$$

When a good wire is available, and this is usually the case, set up the instruments for capacity testing, and take a throw, d, on the broken wire, another, d', on the good wire, and a third, d'', on the good wire with the broken wire connected to it at the far end.

Evidently the throw on the whole broken wire would be $d'' - d' + d$.

Hence where D and X have the same significance as before

$$X : d :: d : d'' - d' + d$$

$$\text{and } X = \frac{dD}{d'' - d + d'}.$$

The location of breaks is much complicated by the presence of poor insulation between ruptured portions, and between other wires. The insulation resistances between these parts should always be taken. If less than one megohm, the results obtained by the capacity tests should not be relied on, and other methods too complex for description here may be resorted to. It seldom pays to open a lead-covered telephone cable for the purpose of joining a few broken wires, the expense of making the splice being usually in excess of the value of the wires.

The location of crosses or grounds is rendered somewhat difficult by the fact that there is nearly always some resistance in the fault itself. If we know the resistance of the defective wire and have no good wire running parallel with it, we may proceed as follows, using a good Wheatstone bridge:

Measure the resistance of one end of the defective wire through the fault to ground. Do the same at the other end. Then calling R the total resistance of the wire (either known or calculated from its size and length), R' the measured resistance from the first end, R'' that from the other end, X the resistance from the first end to the fault, Y the resistance from the second end to the fault, and Z the resistance of the fault, we have:

$$R = X + Y.$$
$$R' = X + Z.$$
$$R'' = Y + Z.$$

Solving these for X and Y we have

$$X = \frac{R + R' - R''}{2},$$

$$Y = \frac{R - R' + R''}{2},$$

which values are independent of the resistance of the fault. Knowing the resistance to the fault, it is easy to compute the distance to it, from the resistance per foot of the conductor.

When a good wire is available, the Varley loop test should be used, as it is more accurate than the method just described.

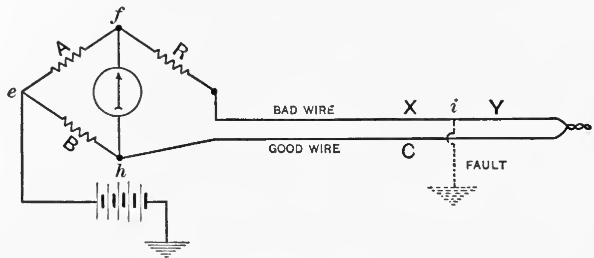


Fig. 357.—Varley Loop Test.

For this a Wheatstone bridge is used, and connected as in Fig. 357. The good and bad wires are joined at their distant ends, and one terminal of the battery connected to the point, e, on the bridge, while the other terminal is grounded. It is not

difficult to see that the partial ground or fault now bears the same relation to the bridge as the point, i, in the diagram of Fig. 342; the rheostat arm now includes the resistance, R, plus the resistance of the bad wire to the fault, while the unknown arm includes the resistance of the good wire, plus the resistance of the bad wire on the other side of the fault.

The equation of the bridge, when balanced, then becomes

$$\frac{A}{B} = \frac{R + X}{C + Y},$$

where R is the unplugged resistance of the rheostat, X the resistance to the fault, Y the resistance beyond the fault, and C that of the good wire.

Now calling L the resistance of the loop consisting of the good and bad wires, we have

$$L = X + Y + C,$$
$$\text{or } C + Y = L - X.$$

Substituting this in the second member of the equation of the bridge, we have

$$\frac{A}{B} = \frac{R + X}{L - X},$$

$$\text{whence } X = \frac{A\,L - B\,R}{A + B},$$

which is independent of the resistance of the fault. When the two ratio arms of the bridge are given equal values we have $A = B$, and the equation for X becomes:

$$X = \frac{L - R}{2}.$$

Sometimes, in ordinary paper cables, a requirement is made that a rubber-covered test wire shall be run through the center of the cable, so that at least one good wire may always be available in testing. Where no good wire is available, a separate wire may be strung to be used as the return in this test.

If the lead wires, from the instruments to the faulty wire, have appreciable resistance, this should be measured, and deducted from the value of X. After this the distance to the fault may be readily obtained from the resistance per foot of the conductor.

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THE END.